INFRASTRUCTURE ASSET MANAGEMENT MODELING THROUGH AN ANALYSIS OF THE AIR FORCE STRATEGIC VISION AND GOALS

THESIS

Marie T. Harnly, First Lieutenant, USAF

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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Marie T. Harnly, BS, BA

First Lieutenant, USAF

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Marie T. Harnly, BS, BA
First Lieutenant, USAF

Approved:

________________/signed/________________________ __17 Jan 12__
Lt Col William E. Sitzabee, Ph.D., P.E. (Chairman) Date

________________/signed/________________________ __17 Jan 12__
Alfred E. Thal, Jr., Ph.D. (Member) Date

________________/signed/________________________ __17 Jan 12__
Maj Kelly M. Hannum, P.E. (Member) Date

________________/signed/________________________ __17 Jan 12__
Maj Vhance V. Valencia, P.E. (Member) Date

AFIT/GEM/ENV/12-M07

Abstract

Effective asset management requires an overarching model that establishes a framework for decision-makers. This research project develops a strategic level asset management model for varying types of infrastructure assets that provides guidance for effective asset management. The strategic model also incorporates Next Generation Information Technology initiatives into a single coherent system in order to streamline the top-down, bottom-up flow of information. The strategic level asset management model is applicable to agencies with a large, varying infrastructure inventory and limited resources. Additionally, this research develops an improved performance modeling tool, a critical component of the strategic model. The improved performance modeling tool objectively prioritizes maintenance and repair projects according to measurable metrics as well as the strategic vision, established goals, and policies. Asset management of Air Force infrastructure provides an example of applicability for this strategic model and improved performance modeling tool; thus, an asset management example of Air Force infrastructure is utilized throughout the research project to demonstrate the utility of the model and the tool. The strategic level model and improved tool enable policy-makers to make decisions that tie goals, infrastructure inventory, condition state, importance and criticality, and budget constraints to system performance. As a result, insight is gained on ways to maximize efficiency and optimize the performance of infrastructure.

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Marie T. Harnly

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INFRASTRUCTURE ASSET MANAGEMENT MODELING THROUGH AN ANALYSIS OF THE AIR FORCE STRATEGIC VISION AND GOALS

1.0 Introduction

Budget constraints and scarce resources have sparked agencies to maximize efficiency when operating and maintaining aging infrastructure. The United States Air Force, for instance, currently manages 139,556 infrastructure assets (facilities, runways, utility lines, and roadways) valued at 263.43 billion dollars (Department of Defense, 2010:11). In 2010, the Department of Defense allocated approximately 2.5 billion dollars, which represents 1.55 percent of the 160.54 billion dollar annual Air Force budget and 0.95 percent of the current replacement value of Air Force infrastructure, to the maintenance and repair of these assets (Department of Defense, 2010:126). In order to optimize the performance of these infrastructure assets, the Air Force Civil Engineer (CE) career field introduced a formalized approach for maintaining infrastructure and labeled this approach asset management (Eulberg, 2008:5-7). Asset management, the foundation of the CE transformation which began in 2007, involves business practices that emphasize management techniques to focus and maximize limited resources (Culver, 2007:4-12). The purpose of asset management is to meet a required level of service in the most cost effective manner while adhering to established goals and policies as well as remaining within budget constraints (Maunsell Project Management Team, 2006:1.3.).

Along with introducing asset management, Air Force senior leadership restructured CE organizations at all levels during the CE transformation (Culver, 2007:4-12). The incorporation of asset management functions at all vertical organizational levels (unit level, major command level, and headquarters level) created an emphasis on planning and implementing asset management principles in daily decision-making. At the unit level, the asset management flight creates and executes asset management plans for an installation. This flight also ensures that required levels of service and key performance indicators are met and that scarce dollars are spent at the right place and right time for maximum effect. The paradigm shift to asset management is most visible in the CE organization restructuring and marks the revolutionary change to an asset management mindset and way of conducting business.

1.1 Problem

Although the asset management culture is present throughout all levels of the corporate structure of CE organizations, there is an absence of a comprehensive framework for numerous types of infrastructure assets to provide guidance for asset management business principles, which results in deficient decision-making tools for CEs. Therefore, a requirement exists for a strategic level model that provides guidance for agencies with large, varying infrastructure sets and limited resources, such as the Air Force. This strategic level model should illustrate the relationships among the components of asset management and integrate these components into a useful decision support system in order to optimize the performance of infrastructure (Schofer, 2010:228-230).

Subsequently, a second requirement has emerged for improved tools that better prioritize maintenance and repair projects and manage infrastructure according to the business principles of asset management. The infrastructure metrics of the Headquarters Air Force prioritization models, the current and recently adopted performance modeling tools that rank order maintenance and repair projects, are subjective and do not measure all of the performance metrics established by Air Force goals and policies. Because of their inherent subjectivity, the priority order of maintenance and repair projects is easily influenced. The prominent issue in regards to the subjectivity of the infrastructure metrics involves Wing decision-makers, who typically influence the priority order of projects. Their actions result in fluctuations in the priority order when leadership changes, which diminish the current and recently adopted tools' validity to objectively compare maintenance and repair requirements for various types of infrastructure at different locations and generate master priority lists for Air Force infrastructure assets. An improved performance modeling tool is necessary to alleviate these issues of the current and recently adopted tools' subjectivity as well as to ensure that the priority order of maintenance and repair projects aligns with the strategic vision and goals of the CE career field.

The establishment of both a strategic level asset management model and improved performance modeling tool is required to provide decision-makers with the appropriate information to develop viable approaches and alternatives. The strategic level framework will enable decision-makers to address issues and answer questions that are essential to infrastructure operations:

- What infrastructure assets (facilities, runways, roadways, and utility lines) does the Air Force own?

- What is the monetary value of the Air Force's infrastructure assets?

- What is the condition of this infrastructure?

- What is the importance of this infrastructure?

- What maintenance and repair are required on these infrastructure assets?

- What effective data management process does the Air Force use to manage this infrastructure?

The improved performance modeling tool will allow decision-makers to address issues and answer a question that is critical to project prioritization:

- What infrastructure does the Air Force need to fix (maintain or repair) first?

The development of a strategic level model and an improved tool will ensure the efficient use of the limited 2.5 billion dollar budget; it will also ensure that all levels of CE organizations follow the principles of asset management (Byers, 2010:3).

1.2 Research Approach

This research will follow a two-phase approach. The first phase will develop a strategic level asset management model for numerous infrastructure types, using the data modeling process and software that incorporates the components of asset management. This model will provide a framework for agencies with a large, varying infrastructure inventory and limited resources to conduct comprehensive management of infrastructure assets. To demonstrate the proposed model's application and validity, a representative sample of Air Force infrastructure will be used to illustrate implementation the strategic model and relationships among the strategic components of asset management.

The second phase will introduce an improved performance modeling tool that focuses specifically on the prioritization model (priority equation) for ranking Air Force maintenance and repair projects, using the improper linear modeling process and data located within the Air Force Real Property Database. This tool will better capture measureable metrics and objectively prioritize maintenance and repair projects for aging infrastructure. Specifically, the measureable metrics of the "20/20 by 2020" goal, which aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020, the Energy Independence and Security Act (EISA) of 2007, which aims to reduce energy usage by 30 percent by the year 2015, and Executive Order 13514, which aims to reduce potable water usage by 26 percent and non-potable water usage by 20 percent by the year 2020, will be incorporated in the priority equation, normalized, and weighted to improve the current and recently adopted performance modeling tools (Congress of the United States, 2007:Section 431; Headquarters Air Force, 2009b:1; Obama, 2009:3). The advantages and disadvantages of three performance modeling tools, the current, recently adopted, and improved tools, will be compared. This comparison will demonstrate that the improved tool prioritizes projects according to the Air Force strategic vision and established goals.

1.3 Research Objectives

The objectives of this research project include the development of both the strategic level asset management model and the improved performance modeling tool. The purposes of this research project are:

1. To introduce a strategic level asset management model that is applicable to agencies with a large, varying infrastructure inventory and limited resources

2. To improve the Air Force performance modeling tools by incorporating infrastructure metrics that tie directly to its established goals and policies

The establishment of a strategic level model for numerous infrastructure types is required to provide decision-makers with a framework that guides the analytical process of asset management and addresses infrastructure challenges. Air Force infrastructure operations are comparable to those of large corporations, public agencies, and universities. The characteristics of the Air Force's distinctive infrastructure inventory impose specific requirements on an overarching asset management model. For example, it is essential that the model transcend facility type as well as state and national boundaries in order for the model to be applied universally to all military installations. Therefore, the establishment of a strategic level model has far-reaching applicability and generalizability to organizations with expansive infrastructure systems, similar inventory characteristics, and limited resources.

The information derived from the improved performance modeling tool (priority equation) will optimize the performance of the Air Force's infrastructure assets and ensure that the priority order of these projects aligns with the strategic vision of the CE career field. This tool's utility will lie in its ability to objectively compare maintenance and repair projects at all installations to determine the projects that most require resource allocation. This updated tool will thus serve as a consistent, objective approach to prioritize projects across all major commands in the Air Force and will allow Headquarters Air Force as well as major commands to focus resources at the most appropriate installation. Ultimately, the aim of this research project is to enable policy-

makers and decision-makers to utilize the strategic level asset management model and improved performance modeling tool to make decisions that tie goals and policies, infrastructure inventory, condition state, importance and criticality, and budget constraints to system performance while objectively prioritizing maintenance and repair projects.

1.4 Overview

This research project progresses through the thesis document in the conventional format. Chapter 2 provides a foundation for asset management and discusses the concepts of asset management, its definitions, and its components that pertain to the research endeavor. The understanding of asset management established by Chapter 2 is essential to implementing the methodologies and developing a strategic level asset management model as well as an improved performance modeling tool. Chapter 3 presents the methodology, the data modeling process, and validation used to develop the strategic level asset management model. Additionally, Chapter 4 presents the methodology, the improper linear modeling process, and verification used to develop the improved performance modeling tool. Chapter 5 discusses the results from the data modeling process and analysis conducted on the strategic level asset management model. Chapter 6 discusses the results from the improper linear modeling process and analysis conducted on the improved performance modeling tool. The analysis of both the model and tool provides observations and insights into infrastructure asset management and its business practices. Last, Chapter 7 presents conclusions along with key findings, limitations, and suggested future research stemming from this research project.

2.0 Literature Review

This literature review establishes an essential foundation of knowledge for the concept of asset management, its components, and its performance modeling tools. It also encompasses the emergence of asset management, its various definitions and models, and infrastructure performance metrics. Understanding how asset management evolved is vital to formulating both a comprehensive asset management model and an improved performance modeling tool that objectively prioritizes maintenance and repair projects. A discussion of asset management definitions follows and provides an overview of what asset management is, how it is defined, and what its concepts are. Next, a discussion of current asset management models establishes how asset management is presently operationalized; however, these current models do not address a large, varying infrastructure inventory. Hence, this discussion highlights the deficiencies of the current models and emphasizes the requirement for a comprehensive asset management model to provide a framework that enables agencies to manage varying types of infrastructure.

The literature review then addresses the requirement for a strategic level asset management model for agencies with large, varying infrastructure sets and limited resources; current asset management models emphasize prevalent asset management components to include in this strategic model. Discussions of each of these components as well as their definitions and concepts follow. The prevalent components are then examined as they pertain to Air Force infrastructure to provide a real-world example and to solidify an understanding of these previously discussed asset management

components; however, one particular Air Force centric component, Air Force performance modeling, does not address the strategic vision, goals, and policies of the organization. Hence, this discussion highlights the requirement for an improved performance modeling tool that aligns with the strategic vision, goals, and policies of the Air Force and incorporates infrastructure metrics that measure the established goals. The foundation that this literature review establishes is essential to developing both a comprehensive asset management model for numerous types of infrastructure assets and an improved performance modeling tool.

2.1 Asset Management Evolution

The evolution of asset management in the public sector began with the Federal Highway Administration (FHWA). In 1998, the FHWA reorganized and created an asset management office to address the ongoing deterioration of the highway system, significant project demand, and a stretched budget (United States Department of Transportation, 1999:5-6). This restructuring resulted from a mindset shift that occurred once the Interstate Highway System was completed in 1992. The FHWA adjusted its focus from an emphasis on new construction to an emphasis on maintenance and management of four million miles of existing interstate infrastructure (highways and roads). Additionally, public expectations increased for government accountability of the FHWA's approximately 41.5 billion dollar annual budget; public scrutiny arose regarding justification of how the capital was spent, what items received resource allocation, and what the outcomes were. As a result of these events, the FHWA reorganized and became one of the first large agencies to implement asset management. Ultimately, the FHWA

adopted asset management principles to maintain, upgrade, and operate infrastructure assets in a cost effective manner.

As discussed previously, Air Force senior leadership reorganized Civil Engineer (CE) organizations in 2007 and incorporated an asset management function at all vertical levels to address similar issues that faced the FHWA: shrinking budget, deterioration of infrastructure, significant infrastructure project demand, and infrastructure challenges, such as allocating resources across asset types and reducing the stock of infrastructure assets as well as the maintenance and repair budget while maintaining a constant level of service and operations. Leadership of both the FHWA and the Air Force introduced the culture change of asset management into its organizations to efficiently manage infrastructure assets and maximize limited resources (Culver, 2007:4-5; United States Department of Transportation, 2003:2-5). Although the specific circumstances and details differed, the situations of both organizations paralleled each other. Both agencies required the strategic process of asset management to support their respective missions and organizational goals.

2.2 Asset Management Definitions

The various definitions of asset management serve to solidify an understanding of this concept. For example, according to Major General Del Eulberg, United States Air Force, Retired (former Air Force Civil Engineer), asset management is "a proactive, fact-based approach that uses standardized processes through a combination of engineering principles and sound business practices" (Eulberg, 2007:2). Asset management strives to manage assets from a holistic perspective and to analyze data in order to make the best

decisions possible with the limited resources available (Eulberg, 2008:5-7). According to the FHWA, asset management is "a cost effective approach to systematically maintain, upgrade, and operate a physical asset." The process consists of business practices and economic theory to improve decision-making for both short and long range planning (United States Department of Transportation, 2003:9).

Cambridge Systems, Inc., transportation asset management specialists, defines asset management as "a strategic approach that aligns strategies, operations, and analysis to ensure the smooth and cost-effective management of infrastructure assets" (Cambridge Systems, Inc., 2002:S-1). Asset management focuses on resource allocation and utilization with the aim of better decision-making based upon quality information and well-defined objectives. The International Infrastructure Maintenance Manual describes asset management as "systematic and coordinated activities and practices through which an organization optimally manages its physical assets, and their associated performance, risks, and expenditures over their lifecycle for the purpose of achieving its organizational strategic plan" (Maunsell Project Management Team, 2006:1.3). These definitions serve to convey varying descriptions of asset management and each is predominant in the field of asset management, depending upon the focus. These definitions also facilitate comprehension of concepts and explain facets of this process.

2.3 Current Asset Management Models

A discussion of current asset management models provides an understanding of how the concepts of asset management are implemented and operationalized. A selection of four current asset management models, each focusing on a different subset of

infrastructure, serves to provide a foundation for the concepts of asset management and its business practices. These four models lead the industry, depending upon the infrastructure focus, are prevalent in the field of asset management, and are used to manage infrastructure from facilities to transportation systems to university campuses. Table 1 consists of a summary of these four asset management models and describes the type of infrastructure that each model focuses on as well as their strengths and weaknesses. Additionally, this discussion of the current models serves to highlight the fact that these models do not address a large, varying infrastructure inventory, thus creating deficient decision support systems for agencies with these infrastructure characteristics.

Table 1. Summary of Asset Management Models

Year	Author	Description	Type	Strengths	Weaknesses
1991	National Association of College and Business Officers	An Overview of the Facilities Portfolio Management Model (Figure 1) includes the four essential steps: • Establish meaningful baseline data • Estimate short and long range renewal needs • Create decision-support models • Report on the facilities portfolio	College/ University Facilities	Focused on facilities at College and University campuses	Limited to public and private agencies with board of directors structure Limited to facilities
1998	United States Department of Transportation	A Generic Asset Management System (Figure 2) includes components in a linear fashion	Interstate Highways	Utilized by government entities	Limited to interstate highways and roadways
2002	Cambridge Systems, Inc	Transportation Asset Management Model (Figure 3) includes the components that contribute to infrastructure performance	Transportation	Focused on performance of transportation systems	Limited to highways and roadways
2006	Maunsell Project Management Team	The Total Asset Management Process (Figure 4) includes strategic, tactical, and operational planning sections	Generic	Useful for varying infrastructure types	Limited to New Zealand's way of conducting business

Figure 1 presents a facility asset management model that is utilized specifically to maintain and repair college and university campuses (National Association of College and Business Officer, 1995:2-8). This model separates the components into four phases (establish baseline, estimate needs, model alternatives, and systematic reporting) to manage infrastructure asset operations. It also balances short and long range needs that represent a university's long-term vision and short-term goals. This model integrates several components of asset management such as budget (funding strategy), infrastructure inventory (compile meaningful information), and condition state (inspect facilities) into a process that is useful for college and university campus infrastructure asset management; however, two limitations exist that prevent its far-reaching applicability. This model encompasses public and private agencies with a "board of directors" structure and focuses mainly on facilities. It does not encompass varied infrastructure types or management structures outside of a board of directors.

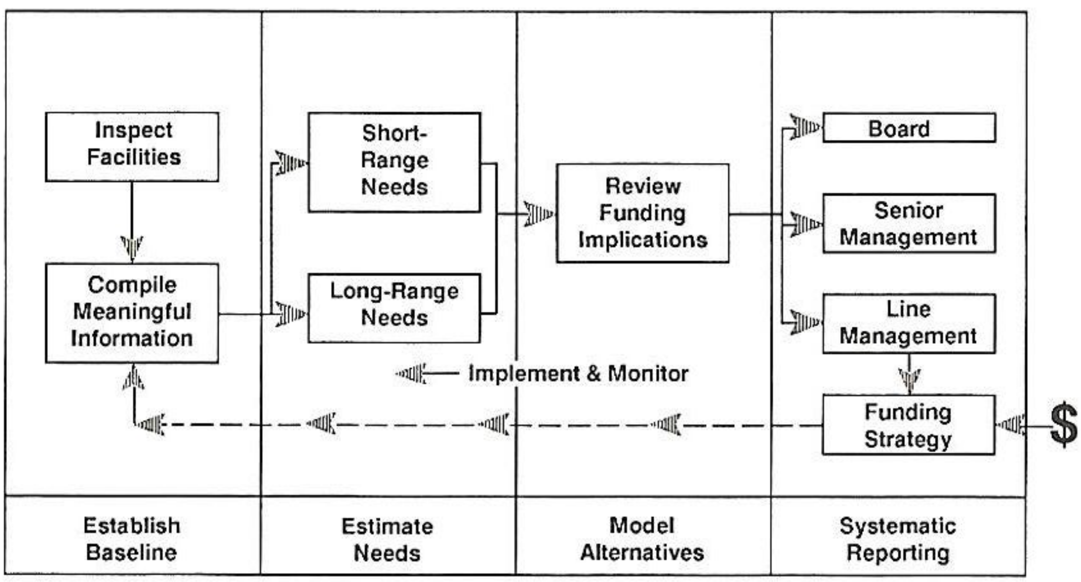

Figure 1. An Overview of the Facilities Portfolio Management Model (National Association of College and Business Officers, 1991:3)

Figure 2 presents an asset management model that is utilized specifically to maintain and repair interstate highway and roadway infrastructure (United States Department of Transportation, 1999:18-25). This model is composed in a linear fashion to progress from one component to the next and includes a feedback loop to begin the process again. It also balances the budget with goals and policies to evaluate alternatives. The scheme of this model, similar to that shown in Figure 1, integrates several components of asset management such as asset inventory, condition, performance modeling, budget, short and long range plans, and implementation into a business process that guides transportation asset management. The utility of this model is limited to interstate highway and roadway infrastructure. The model does not incorporate numerous infrastructure types and as a result does not apply to the entire spectrum of infrastructure asset management.

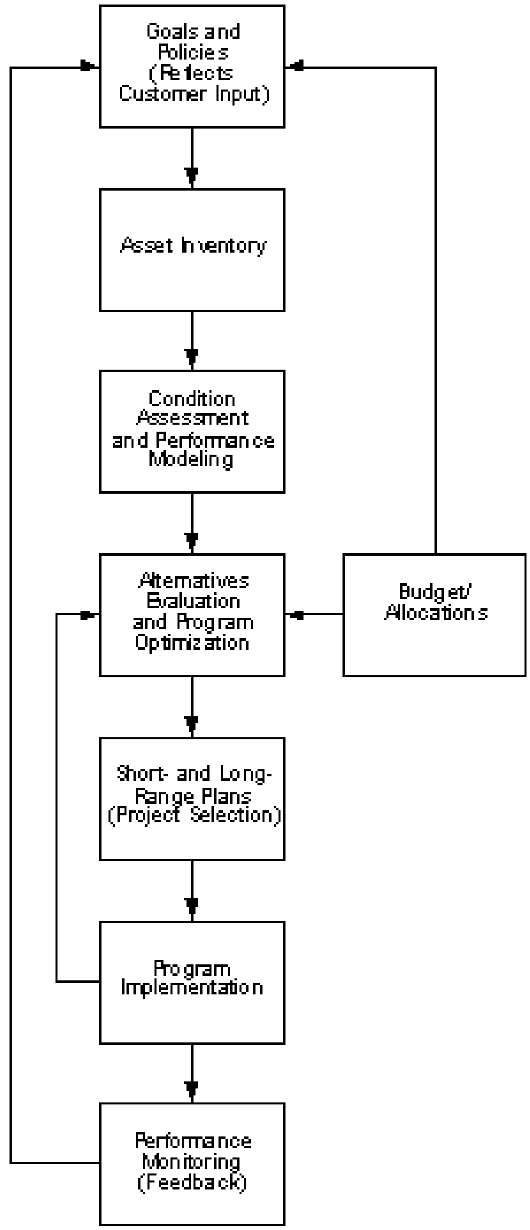

Figure 2. A Generic Asset Management System (United States Department of Transportation, 1998:20)

Figure 3 presents an asset management model that is similar to the model illustrated in Figure 2 and that is utilized specifically to maintain and repair transportation infrastructure (Cambridge Systems, Inc., 2002:1.4-1.7). This model illustrates the components that contribute to transportation infrastructure performance and separates

these components into two groups, overarching activities on the left and their components on the right. Many of these components exist in the two previously discussed models (Figure 1 and Figure 2): performance modeling, policies, and budgets; however, this model incorporates additional entities, such as data collection, scenario generation, decision analysis (including risk management), and management actions into the transportation asset management process. Similar to Figure 2, this model does not encompass numerous infrastructure types because it is limited to highways and roadways systems. As a result, this model also does not apply to the entire spectrum of infrastructure asset management.

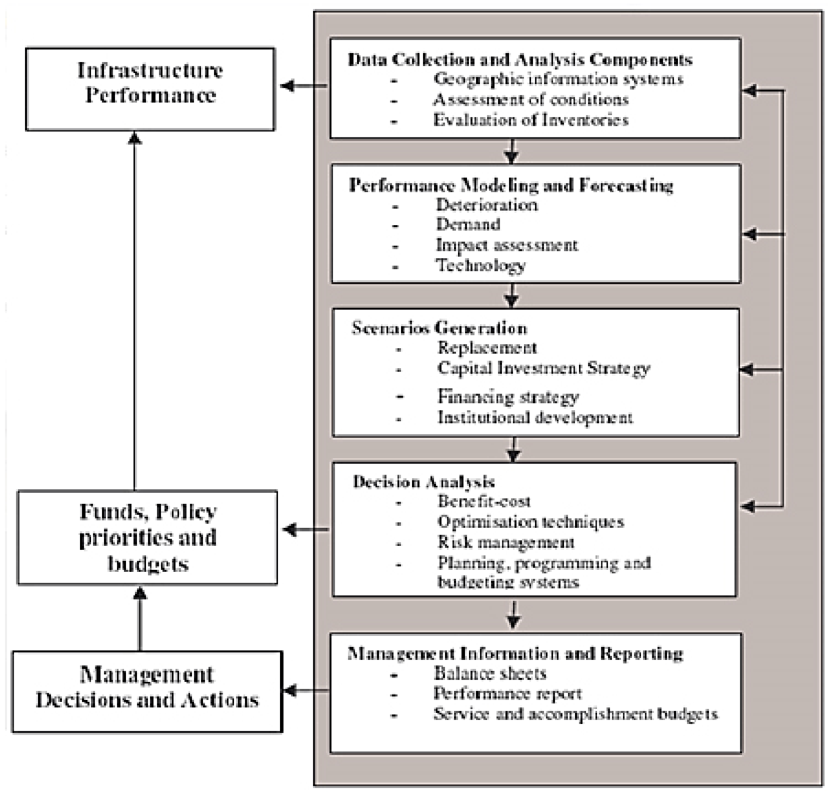

Figure 3. Transportation Asset Management Model (Cambridge Systems, Inc., 2002:1.5)

Figure 4 presents the total asset management process through a model that incorporates the strategic, operational, and tactical planning sections. This model originated in New Zealand and interchanges tactical and operational from the American military perspective of these two planning sections (Maunsell Project Management Team, 2006:1.2-1.8). It is separated into four sections and focuses on strategic asset management as a decision-making tool by including mission, vision, objectives, and strategy elements in the process. As a result, this model concentrates on asset management planning and philosophy as well as the framework it provides to the decision-maker. Although this model is useful for varying infrastructure types, it emphasizes the typical way that business is conducted in New Zealand, which severely diminishes its applicability to agencies in the United States.

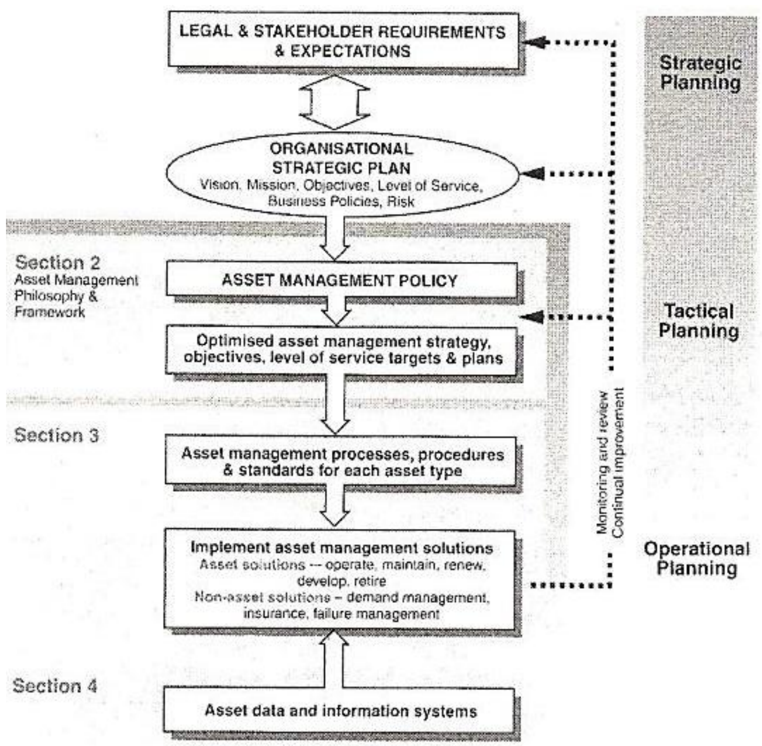

Figure 4. The Total Asset Management Process (Maunsell Project Management Team, 2006:1.6)

These four industry leading asset management models focus on a particular type of infrastructure or a specific management structure. The lack of a comprehensive model for numerous infrastructure types results in agencies constructing piecemeal models that suit their needs for adequate decision-making tools. The deficiencies of the current models highlight the absence of a strategic level asset management model for agencies with a large, varying infrastructure inventory and limited resources. As a result, these deficiencies emphasize the requirement for a comprehensive model that provides a framework to guide the business principles of asset management for agencies with a large, varying infrastructure inventory and limited resources.

2.4 Requirement for a Comprehensive Asset Management Model

Decision-makers balance performance expectations with attainable goals, available budgets, performance metrics, and organizational policies in order to implement viable cost-effective strategies (Australian National Audit Office, 1996:5-7). However, a requirement exists for a strategic asset management model that creates a decision-making framework for numerous infrastructure types, guides the analytical process of asset management, and addresses infrastructure challenges. Four challenges sparked this requirement for a strategic level model: financial factors as opposed to technical factors, short-term planning as opposed to long-term planning, network as opposed to individual projects, and allocating resources across asset types (Vanier, 2001b:39-40). The financial factors, such as cost of maintenance and repair projects, are weighed against technical factors, such as structural quality of roofs and foundations, when implementing a solution. This constant challenge is exacerbated by a shrinking budget and by the

monetary cost of necessary projects exceeding the funds available for these projects. Under these circumstances, "asset managers must allocate funds among competing, yet deserving requirements" (Vanier, 2001a:4).

Short-term remedies are evaluated against long-term goals. A short-term fix may not be the most economical solution and a long-term strategy may not be the timeliest solution (Vanier, 2000a:40-52). The short-term cost may not achieve the savings of a long-term fix; however the decision to select a particular remedy for an infrastructure problem hinges on the availability of funding. A short-term fix may be selected, even if that fix is not the most advantageous solution due to the unavailability of long-term funding. The difficulty in balancing short and long-term factors significantly increases with rapidly changing targets and goals. These challenges hinder the ability to assess and delineate short-term as well as long-term budgets and priorities, creating an increasingly difficult task.

Additionally, infrastructure is an integrated system with individual components that function independently and in conjunction with other systems (Vanier, 2000b:3-14). The interconnectedness of infrastructure links assets into a complex system of interrelated elements (Robinson, Woodard, and Varnado, 1998:61). This concept of infrastructure coupling correlates the state of one infrastructure asset to the state of another, which creates an interdependency between the two (Rinaldi, Peerenboom, and Kelly, 2001:18-20); however, most maintenance management systems (MMS) assess only individual components or isolated projects, instead of accounting for network goals and coupling effects. These individual projects are weighed against networks in which

infrastructure is constrained by the weakest link or networks where parts should be replaced simultaneously in neighboring systems.

Last, budget constraints for maintenance and repair projects require decision-makers to allocate resources across asset types while considering the value an asset has to an agency's operations and the current condition of the infrastructure. The difficulty in allocating resources across numerous types of infrastructure assets is driven by the issue of objectively comparing the worth and importance of infrastructure assets. Rapidly changing leadership and goals along with these issues create an increasingly challenging task, to delineate among assets and determine which most require resource allocation. The contending factors of financial as opposed to technical, short-term planning as opposed to long-term planning, network as opposed to individual projects, and allocating resources across asset types provide challenges and opportunities for decision-makers. Agencies with a large, varying infrastructure set and limited resources require a strategic asset management model that properly balances these infrastructure challenges by creating a useful decision support system to guide the analytical process of asset management.

2.5 Components of Infrastructure Asset Management

This section discusses numerous components of asset management models and, as an example, examines how these components pertain to the Air Force. The prevalent infrastructure asset management components that are included in the proposed model for numerous infrastructure types are derived from the four previously addressed models. The following strategic components are discussed in the subsequent sections:

- Strategic Vision
- Infrastructure Inventory
- Condition State
- Importance and Criticality
- Performance Modeling
- Goals and Policies
- Budget
- Alternative Selection
- Operational Plan Development
- Execution
- Feedback

2.5.1 Strategic Vision.

A strategic vision for asset management provides agencies with a meaningful approach to complex infrastructure systems. Policy-makers develop and establish a strategic vision that provides a framework to guide and shape the various components of asset management (CDM, 2009:2-7). Articulation and implementation of the strategic vision occurs both horizontally and vertically throughout the organization. Knowledge of the desired end state allows decision-makers to prudently dedicate resources to the operation, maintenance, and repair of infrastructure assets. This strategic vision creates an umbrella under which the operational aspects of data collection, budgets, policies, and goals can be aligned in order to utilize the latest asset management techniques (Australian National Audit Office, 1996:21-28). Ideally, it influences these operational aspects of

asset management and drives infrastructure inventory data requirements, condition state data requirements, importance and criticality data requirements, resource allocation, and policy decisions. The strategic vision, therefore, guides the integration of data and performance modeling tools as well as the exploration of various scenarios to develop a viable course of action.

2.5.2 Infrastructure Inventory.

Decision-makers require the right level of information to simulate potential scenarios and to develop feasible approaches and alternatives. The purpose of maintaining an infrastructure inventory is to determine what assets are owned and where they are located (Vanier, 2001a:6-7). Geographic information systems (GIS) relate assets to their physical location and MMS store pertinent information about infrastructure to provide an accurate, holistic view of the asset management portfolio. Ideally, agencies minimize their requirements and cost for data collection, collect the correct data, and avoid redundant data collection. However, collecting and managing inventory data for agencies with a large, varying infrastructure set are both time consuming and costly (Rasdorf, Hummer, Harris, and Sitzabee, 2009:91-99). Yet without accurate data, determining a precise infrastructure inventory of what an agency owns and where it is located is nearly impossible.

2.5.3 Condition State.

An infrastructure inventory serves as the backbone for valid condition states of infrastructure assets. Because infrastructure systems are in a constant state of decay, the condition state represents a snapshot of dynamic infrastructure assets (Government Accountability Office, 2007:56). Technology remains the primary limitation in

collecting, updating, and maintaining system inventory and condition information in an efficient manner. As technology continues to evolve, so does the ability for operators and maintainers to compile and update infrastructure inventory and condition data (National Association of College and University Business Officers, 1995:22-28). The objective of collecting condition state data is to understand the current maintenance and repair required on infrastructure and to predict the future state of assets (Ugarelli, Venkatesh, Brattebo, Di Federico, and Saegrov, 2010:113). Ultimately, the goal is to accurately assess the condition state as it relates to the performance standards defined by a strategic vision.

The current condition state of infrastructure should indicate the monetary worth, structural integrity, and deferred maintenance and repair work required on that asset. The worth of infrastructure assets can be described variously, such as the depreciated cost of an asset calculated in present day dollars, the current replacement value (CRV) (cost of replacing the asset today), or the market value of the asset if it were sold on the market today (Vanier, 2000b:10-13). The structural integrity is assessed by periodic inspections of infrastructure systems (Ugarelli et al., 2010:113). These condition assessments along with automated sensors measure the function and safety of the system's structural components (Earl, 1997:280-282). Additionally, deferred maintenance is defined in industry as the total dollar amount of existing maintenance and repair projects required to restore infrastructure systems to an acceptable condition state (Association of Higher Education Facilities Officers, 2003:25). If maintenance is not completed and deferred to the next year, then the cost of maintenance and repair projects compounds due to inflation as well as increased maintenance and repair costs resulting from further system

degradation (Vanier, 2000a:49-52). Monetary worth, structural integrity, and deferred maintenance and repair provide key pieces of information that determine the remaining service life of infrastructure assets and are measurable metrics for performance modeling tools that relate performance standards to the strategic vision.

2.5.4 Importance and Criticality.

An infrastructure asset's criticality characterizes its importance or business value to an agency's operations. The two objectives of collecting infrastructure importance and criticality data are: to understand the impact that an incapacity or destruction of infrastructure assets would have on operations and to establish a relative order of significance among assets to allocate limited resources (Department of Homeland Security, 2009:1-3). The importance and criticality infrastructure metric should indicate the intradependencies within infrastructure, interdependencies among infrastructure, and the scope of operations affected by the inoperability of a particular asset (Antelman, 2008:1). One infrastructure metric that captures these aspects is the mission dependency index (MDI), which quantifies the extent that infrastructure assets' operations are able to be interrupted, relocated, and replaced. It also develops a risk-based metric from responses to structured interview questions that link infrastructure to the mission (Antelman, 2008:1). Ultimately, the goal in collecting and capturing importance and criticality data on infrastructure assets is to accurately assess the impact on operations as it relates to the strategic vision.

2.5.5 Performance Modeling.

Performance modeling is the primary tool to understand the maintenance and repair requirements of infrastructure systems (McElroy, 1999:2-3). These tools require

accurate and reliable data in the form of infrastructure inventory, condition state, and importance and criticality. The goal in shaping our maintenance and repair decision is to choose the most economical approach (from a life-cycle standpoint) to answer the question, what should be fixed first? (Sitzabee, Hummer, and Rasdorf, 2009a:198; Sitzabee, Rasdorf, Hummer, and Devine, 2009b:288-293; Vanier, 2001a:8-9). Several performance modeling tools integrate various metrics, such as the facility condition index (FCI) and MDI to gain a holistic perspective of the performance of infrastructure assets and to prioritize maintenance and repair projects. The FCI is a performance indictor of the building's overall economic health (Uzarski and Burley, 1997:368). Specifically, it is a monetary-derived approach that compares deferred maintenance and repair work required to remedy existing infrastructure deficiencies to CRV. The equation to calculate a FCI is expressed in Equation (1) (Association of Higher Education Facilities Officers, 2003:25; Department of Defense, 2009:12-15).

$$FCI = (deferred\ maintenance\ and\ repair)/CRV \qquad (1)$$

Performance modeling tools and measureable metrics provide an analytical process for project prioritization and justify allocations of a limited budget (McElroy, 1999:6-7). These tools, in essence, guide decisions that are related to the established strategic vision. Thus, a dependency exists between the performance modeling tool and the strategic vision. This relationship ensures that the measureable components of the tool provide decision-makers with the necessary information to align viable approaches with the strategic vision. The ultimate goal is to enable decision-makers to make informed, performance-based decisions that link the goals, policies, and budget to known aspects of system attributes (infrastructure inventory, condition state, and importance and

criticality) and performance (metrics and modeling tools). The intent is to relate the infrastructure inventory, condition state, and importance and criticality to the goals, policies, and budget while allowing the strategic vision to influence and guide all of these operational aspects.

2.5.6 Goals and Policies.

Goals and policies arise from and align with the strategic vision to convey how an agency is managing its assets as well as translate an organization's strategic vision into specific, relevant targets (Maunsell Project Management Team, 2006:1.7). They dictate an agency's level of service (LOS) expectations and drive the key performance indicators (KPI). They also indicate the items to focus upon at the operational and tactical levels as well as methods of execution for these items of interest. These specific targets and focus items represent benchmarks that propel agencies toward achieving their desired, long-term objectives. Both of these components, goals and policies, should influence and guide the approach selected by decision-makers, which is limited by available funding.

2.5.7 Budget.

Budgets dictate the availability of resources for infrastructure maintenance and repair projects. In essence, budgets define constraints for selecting alternatives and limit project execution. The Federal Facilities Council recommends agencies set an annual maintenance and repair budget at two to four percent of the CRV of infrastructure assets to adquately maintain infrastructure assets with minimal backlog (Vanier, 2001b:38-40). Two percent is advised, if minimal backlog exists, but this estimate is conservative. Four percent is agressive, but this amount is recommended if a large amount of backlog exists. The completion of necessary maintenance and repair depends upon sufficient funding and

relies on an adequate budget to implement these asset management business practicies (Frangopol, Lin, and Estes, 1997:1394-1397). An appropriate level of funding provides decision-makers the ability to enact viable approaches that further the achievment of goals and align with the strategic vision.

2.5.8 Alternative Selection.

Alternative selection explores options associated with infrastructure assets to determine which approach is in the agency's best interest. It entails examining and analyzing information from the performance modeling tool, goals, policies, and budget to determine the most advantageous solution. At this step in the model, the decision-makers decide upon the preferred resolution from the data provided (Cable and Davis, 2004:4-6). Typically, there are five viable options to select from: demolition, renovation, capitalization, maintenance and repair, or status quo. Each alternative represents a possible resolution and at times the optimal solution involves a combination of these alternatives (National Research Council, 1998:21-25). The optimal solution is derived from an informed, analytical process, aligns with the strategic vision, and is then implemented.

2.5.9 Operational Plan Development.

The purpose of operational plan development is to examine how the preferred course of action impacts an agency's infrastructure from a second and third order effect perspective. Once an optimal solution is determined, operational plan development considers how to leverage efficiency from infrastructure networks and how the proposed course of action affects other aspects of these assets (Coullahan and Siegfried, 1996:8-9). This component of the model attempts to utilize limited resources in the most effective

manner by exploring the various effects of a decided upon course of action and the resulting gains in efficiencies from infrastructure networks (Grigg, 2003:1-12). Along with addressing how the optimal solution affects current maintenance and repair projects, operational plan development analyzes the effects on future planning and tangential endeavors.

2.5.10 Execution.

Once decision-makers have determined the appropriate approach during alternative selection and the impacts of the selected course of action during operational plan development, the next step is execution. Project implementation occurs during this component. The intent of execution is to synchronize the previously discussed components in order to complete projects (Cable and Davis, 2004:4-6).

2.5.11 Feedback.

Asset management models are iterative, and the feedback loop allows for decision-makers to reflect upon past efforts and start again (National Association of College and University Business Officers, 1995:6). The initial cycle through this asset management model provides the basis for subsequent cycles and influences future decisions (Maunsell Project Management Team, 2006:1.6). Once a project is executed, decision-makers analyze the results, address any issues, and start to work through the model again at the appropriate phase. Depending upon the circumstances and an agency's climate, decision-makers may transition from execution to a previously discussed component (infrastructure inventory, condition state, importance and criticality, goals and policies, budget, or operational plan development) through the feedback loop, in order to once again cycle through the asset management model. Thus, the feedback

loop allows decision-makers to address changes that occur in the infrastructure inventory, condition state, importance and criticality, goals and policies, as well as budget and iterate through the asset management model.

2.6 Components of Air Force Infrastructure Asset Management

To solidify an understanding of these asset management components, they are discussed as they pertain to Air Force infrastructure to provide a real-world example. This example addresses the details of each component specifically for the Air Force. It also allows further comprehension of these components and concepts from a real-world perspective. The background into Air Force infrastructure asset management furthers this research endeavor that first develops a strategic asset management model for agencies with large, varying infrastructure sets and second provides an improved Air Force performance modeling tool.

2.6.1 Air Force Strategic Vision.

Department of Defense (DoD) strategic level documents provide overarching guidance that the Air Force implements through its own strategic vision and operations (Department of the Air Force, 2010:1). This research project focuses on a level vertically below the DoD strategic vision. Specifically, it focuses on the Air Force strategic vision; however, the DoD strategic vision shapes the Air Force strategic vision. Thus, an examination of DoD strategic level documents is necessary prior to discussing Air Force strategic level documents.

Several DoD strategic level documents guide asset management business principles in the Air Force. For example, Executive Order 13327 states that it is "policy

of the United States to promote the efficient and economical use of America's real property assets and to assure management accountability for implementing Federal real property management reforms" (Bush, 2004:5897). Following this policy, infrastructure assets require asset management processes that establish clear goals and objectives as well as improve policies and levels of accountability. A White House Memo asserts that "the Federal Government is the largest single property owner in the United States and manages more real estate than necessary to effectively support its programs and mission" (Obama, 2010:1). Agencies are directed by this memo to accelerate efforts to eliminate excess properties and to examine real property assets by utilization and occupancy rates, annual operating cost, energy efficiency, and sustainability.

Additionally, the Office of Management and Budget affirms in the fiscal year 2012 budget guidance that "agencies should not simply reduce spending across the board, but rather should aim to restructure their operations strategically" (Office of Management and Budget, 2010:1). This guidance reflects efforts to optimize operational capability of infrastructure and incorporates asset management processes in daily business practices. These three strategic level documents introduce the paradigm shift to asset management, frame the strategic vision for the DoD, and lay the foundation for the Air Force strategic vision. For instance, according to the strategic vision of the Air Force Civil Engineer, civil engineers seek to "provide…efficient, sustainable installations by using transformational business practices and innovative technologies" (Office of the Air Force Civil Engineer, 2011:1). This strategic vision highlights the use of asset management principles in daily operations and currently guides data collection, budgets, policies, and goals for the Air Force.

2.6.2 Air Force Infrastructure Inventory.

The Air Force infrastructure inventory assesses what assets the Air Force owns and where they are located. For example, the Air Force owns an incredibly diverse set of constructed facilities and infrastructure assets ranging from dormitories to aircraft hangars to warehouses (National Research Council, 1998:1). This infrastructure supports a myriad of government functions and is located on numerous continents. The 139,556 infrastructure assets in the Air Force's inventory span decades, and sometimes centuries, of building design and construction technologies (Department of Defense, 2010:11).

The Air Force collects and maintains data for its infrastructure inventory and requires minimal labor for data collection as well as calculation, condition state (discussed in Section 2.6.3), and importance and criticality (discussed in Section 2.6.4) of infrastructure in order to generate a snapshot of its assets; however, considerable information technology (IT) issues exist because current data management systems do not effectively communicate with each other and data is entered multiple times into multiple data management systems (Thomas, 2009:6). The MMS for the strategic level, for instance, are not compatible with the MMS for the tactical level. As a result, individuals develop and maintain spreadsheets and databases of their own to compensate for inadequate systems. The Air Force approved the Next Generation Information Technology Program Management Plan, in response to these issues. This plan transforms current IT to better support asset management business processes in order to provide decision-makers with streamlined information to make strategic decisions (Earle, 2010:12). The plan focuses on six requirements (no more redundant data entry, high-tech data collection, simplified data calls, on-site supply orders, automated real property

installed equipment requirements, and total cost information in one place) in order to achieve this objective. The key themes from these requirements emphasize the unnecessary redundancy of data entry and the importance of transparent data for all vertical levels. The overarching goal is to enable efficient and effective collection, maintenance, and analysis of data to provide a view that encompasses all of the infrastructure assets at every installation.

2.6.3 Air Force Condition State.

Along with an inventory of infrastructure, the Air Force captures condition state data to accurately assess the current and future state of assets. The Air Force collects condition state data in a MMS, called the Interim Work Information Management System (IWIMS), tailored specifically for military operations. This MMS captures aspects such as CRV, condition assessments, and deferred maintenance and repair to provide essential information for the decision-making process. Deferred maintenance, according to the DoD regulations, is defined as "maintenance that was not performed or scheduled when it should have been, and as a result, was delayed for a future period" (Department of Defense, 2009:12-13). The Air Force carries over approximately 9.3 billion dollars of maintenance and repair backlog each year, which amounts to 3.5 percent of its CRV (Government Accountability Office, 2008:5). This quantity of deferred maintenance and repair is above the industry standard of one to two percent residual from year to year, indicating that the Air Force carries almost double the recommended amout of maintennace and repair backlog each year (Government Accountability Office, 2008:4-5). Condition state data allow decision-makers to understand the current requirements and to predict the future requirements of Air Force infrastructure assets.

2.6.4 Air Force Importance and Criticality.

The Air Force also captures importance and criticality data to accurately assess the relative significance of assets when allocating limited resources and the impact on operations when assets are inoperable. The Air Force collects importance and criticality data in a MMS. The MDI is the specific infrastructure metric that the Air Force uses to represent these data and determine the value a building brings to an agency's mission performance (Government Accountability Office, 2007:56). The MDI is on a zero to 100 scale with zero reflecting infrastructure that is not mission critical, and 100 representing infrastructure that is absolutely necessary for the mission (Antelman, 2008:1-5). Air Force assets that are considered significant or critical to the mission receive an MDI score of 70 or above. Importance and criticality data enable decision-makers to understand the link between infrastructure assets and mission accomplishment.

2.6.5 Air Force Performance Modeling.

2.6.5.1 Current Air Force Performance Modeling Tool.

Performance modeling for the Air Force serves as the primary tool to prioritize maintenance and repair requirements and utilizes the FCI and MDI metrics. For instance, Headquarters Air Force developed the current performance modeling tool. The Air Force currently uses Equation (2) to prioritize maintenance and repair projects (Headquarters Air Force, 2009a:14-15). The FCI and MDI are multiplied together and account for the initial relative priority score. The commander adjustment adds or subtracts up to 10 points to adjust the initial priority in order to account for subjective factors.

$$Priority = (FCI \times MDI) +/- Commander\ Adjustment \tag{2}$$

The FCI is used to indicate the relative physical condition of an infrastructure asset (Association of Higher Education Facilities Officers, 2003:24-28). The FCI is on a zero to one scale with zero reflecting no backlog of maintenance and repair, and one representing a backlog of maintenance and repair equal to the building replacement value (Uzarski and Grussing, 2008:1-3). According to industry standards (Vanier, 2001a:1-4), an

- FCI under 0.05 is considered good
- FCI between 0.05 and 0.10 is considered fair
- FCI between 0.10 and 0.15 is considered poor
- FCI over 0.15 is considered extremely problematic

The DoD categorizes the condition state of its infrastructure assets into four quality ratings or Q-ratings using Equation (3) (Moy, 2007:3).

$$Q\text{-}Rating = (1 - FCI) \times 100 \tag{3}$$

According to Air Force standards (Moy, 2007:3), a

- Q-Rating between 100 and 90 (FCI between 0.0 and 0.10) is considered good and designated as band Q-1
- Q-Rating between 89 and 80 (FCI between 0.11 and 0.20) is considered fair and designated as band Q-2
- Q-Rating between 79 and 60 (FCI between 0.21 and 0.40) is considered poor and designated as band Q-3
- Q-Rating between 59 and 0 (FCI between 0.41 and 0.0) is considered failing and designated as band Q-4

The Q-Rating categories differ greatly from the recommended industry standard and grant extreme latitude to the condition of Air Force infrastructure in regards to which

assets are considered in good, fair, poor, or extremely problematic (failing) condition. For instance, an infrastructure asset with a 0.17 FCI, which is considered extremely problematic according to industry standards is considered fair according to Air Force standards. Additionally, the Air Force focuses maintenance and repair projects on infrastructure assets in the failing category in an attempt to reduce the deferred maintenance and repair on these assets and extend their service life (Government Accountability Office, 2007:56).

Ideally, a balance between accuracy of data and cost as well as labor required to calculate infrastructure metrics must be achieved. Although the FCI aims to quantify the overall economic health of infrastructure and requires minimal labor for data collection as well as calculation, the deferred maintenance and repair work portion (numerator of Equation (1)) is easily influenced (Uzarski and Grussing, 2008:3-4). The deferred maintenance and repair backlog is formulated from the infrastructure inventory and the condition state data to determine what maintenance and repair projects are required on infrastructure assets. The accuracy of this backlog depends upon the thoroughness of the condition assessments and how proactive the infrastructure users are to inform engineers of necessary maintenance and repair. With this process of relying on individuals' opinions to decipher a threshold for maintenance and repair projects, certain deficiencies may be ignored or overlooked if the probability of funding or completing the project is low (Uzarski and Grussing, 2008:2-4). The deferred maintenance and repair calculation is also based upon deficiency inspection reports from years past that may misrepresent the backlog due to the continual degradation of system components, thereby causing the scope of corrective actions to be less accurate (National Association of College and

University Business Owners, 1991:26-28). Thus, depending upon the amount of deferred maintenance and repair documented on a particular infrastructure asset, the numerator or deferred maintenance and repair work portion of the FCI can be influenced to appear as a significant or insignificant amount. For instance, by completing incredibly thorough assessments on an infrastructure asset, the deferred maintenance and repair portion of the FCI can be increased, which is advantageous if one is advocating for money; or the deferred maintenance and repair portion of the FCI can be decreased by failing to complete condition assessments at all, which is advantageous if one is asserting infrastructure assets are maintained impeccably (Uzarski and Grussing, 2008:2-4).

Agencies should not rely on the FCI as the sole infrastructure metric that represents the priority order of maintenance and repair projects; however industry studies and research asserts that the "FCI is an effective metric for ranking the condition of assets and using it for comparative analysis" of the condition state of infrastructure (Vanier, 2001b, 7-8). The FCI provides enough certainty to achieve the delicate balance between accuracy of data and cost as well as labor required to calculate a condition state metric; however, in the case of the Air Force and its current performance modeling tool, the FCI infrastructure metric (calculated by Equation (1)) of Equation (2) assigns points based upon the four Q-rating categories (Equation (3)). For example, facilities in the Q-1 range receive a specified amount of points. As a result, this metric does not truly reflect the condition state of an infrastructure asset.

The MDI strives to quantify an infrastructure asset's interruptability, relocatability, and replaceability; yet the score is the product of interpolation from a few Air Force installation assessments and data from Navy installation assessments. These

installation assessments consisted of structured interviews from numerous decision-makers at each installation that encompass the impact upon the mission if a particular infrastructure asset is no longer functional (Antelman, 2008:1-5). These MDI scores are then compared among infrastructure with identical category codes (same CATCODE) to statistically determine a standard MDI score that applies to the same type of infrastructure across all Air Force installations. This process allows for broad comparisons among the importance and criticality of different types of assets, instead of comparing the importance and criticality among specific assets. With this process of interpolation and standardizing scores based upon CATCODE type, the importance and criticality of an infrastructure asset may be misrepresented as a higher or lower MDI score.

Another issue that the Air Force faces with regards to Equation (2) is the frequent turnover of leadership. Commanders typically hold their positions for two years and then are succeeded by another individual. This perpetual flux in personnel results in frequent adjustments and changes to the strategic vision and goals. Additionally, the commander adjustment metric of Equation (2) is based upon the preferences of the commander. The points allocated toward the priority score for this metric change as commanders change, which causes the priority order for maintenance and repair projects to change as well. For example, a commander prioritizes rubber removal for a runway as the number one project and replacement of carpeting in a dormitory as the fiftieth project. Then, a new commander prioritizes the runway project as the fiftieth project and the carpeting project as the number one project. This shift in the priority order demonstrates that the priority of these projects is based on a subjective opinion; thus, neither project is critical. Natural

fluctuation occurs from one opinion to the next; however, great fluctuations in priority order from one opinion to the next mitigate the argument that the priority order is a true reflection of the projects that most require resource allocation.

The inherent subjectivity and misrepresentations built into the entire priority equation (Equation (2)) from each of its metrics (FCI, MDI, and Commander Adjustment) and the combination of these metrics to produce a priority score diminish the validity of Equation (2) to objectively compare numerous infrastructure types at different locations and generate master priority lists for Air Force infrastructure assets. Equation (2) multiples the FCI and MDI together for an initial priority score, which combines these two metrics to mathematically skew this initial priority score. For example, a facility with a FCI of 0.35 (Q-3, poor) and a MDI of 50 (a moderate mission dependence) receives the same initial priority as a facility with a FCI of 0.175 (Q-2, fair) and a MDI of 100 (absolutely critical to mission accomplishment). Ideally, the performance modeling tool, goals, policies, as well as budget shape and guide the optimal solution as it relates to the strategic vision.

2.6.5.2 Recently Adopted Air Force Performance Modeling Tool.

Headquarters Air Force recently adopted a new performance modeling tool for Air Force use that incorporates several infrastructure metrics. Decision-makers will utilize the current Air Force performance modeling tool (Equation (2)) to prioritize maintenance and repair projects until implementation of the recently adopted performance modeling tool (Equation (4)) in 2013 (Headquarters Air Force, 2011:4-10).

$$\begin{aligned}\mathit{Priority} &= 0.15(\mathit{Health, Safety\ and\ Compliance}) + 0.10(\mathit{FCIx100}) + 0.15(\mathit{Standardized\ MDI}) \\ &+ 0.20(\mathit{Local\ Mission\ Impact}) + 0.15(\mathit{Cost\ Efficiency}) + 0.25(\mathit{Service\ Quality}) \qquad (4)\end{aligned}$$

Each metric ranges from a zero to 100 scale and is weighted with 15 percent allotted to health, safety, and compliance, 10 percent allotted to FCI, 15 percent allotted to the standardized MDI, 20 percent allotted to local mission impact, 15 percent allotted to cost efficiency, and 25 percent allotted to service quality.

Issues that involve the health or safety of individuals require immediate correction to alleviate the deficiency; the health, safety, and compliance metric ensures that projects earn points for severe, existing conditions of infrastructure. The FCI infrastructure metric (calculated by Equation (1)) of Equation (4) assigns points based upon the four Q-rating categories. Equation (4) separates the MDI into the standard MDI, the MDI used in Equation (2), and a local mission impact that determines an infrastructure asset's importance and criticality to the local mission, based upon interviews with commanders. The cost efficiency metric attempts to incorporate energy and square footage into the priority equation; projects earn points based upon the energy or space efficiency they will achieve. Last, the service quality metric allots points to decision-makers, similar to the commander adjustment in Equation (2), to account for subjective factors.

Although the recently adopted equation encompasses six factors (instead of three for the current performance modeling tool), the complexity, subjectivity, and misrepresentation of the metrics as well as man-hours and cost required to calculate the metrics diminish the practicality of this recently adopted equation. This equation obtains accuracy of data by requiring a tremendous amount of manpower and a large budget to generate a priority score. For instance, the issues with the metrics of Equation (4) include the health, safety, and compliance metric, which relies on risk assessment codes as well

as compliance with numerous regulatory codes to determine the danger level and severity of existing conditions. The Air Force is able to minimize threats to health and safety almost immediately with in-house employees, rather than waiting for the project prioritization, approval, and completion process. In the rare instances that in-house employees are not able to remedy health, safety, and compliance issues, the service quality infrastructure metric allows decision-makers to allocate resources toward these issues and the mission dependency index accounts for issues that affect mission accomplishment. Thus, the redundancies in the prioritization process among in-house remedies and other infrastructure metrics of the recently adopted performance modeling tool diminish the health, safety, and compliance metric's purpose. The FCI metric involves the same previously discussed issues (Section 2.6.5.1), especially the Q-rating, which separates the FCI into four categories and assigns points based upon these categories. Infrastructure assets in the Q-1 band receive 0 points, assets in the Q-2 band receive 40 points, assets in the Q-3 band receive 80 points, and assets in the Q4 band receive 100 points toward the FCI score. As a result, this metric does not truly reflect the condition state of an infrastructure asset.

Additionally, the MDI accounts for both the standardized MDI and local mission impact. The standardized MDI allows for the identical type of infrastructure assets (same CATCODE) to receive the same MDI score across the Air Force and involves the same previously discussed issues (Section 2.6.5.1). The local mission impact produces a MDI score tailored to the mission and needs of each Air Force installation and incorporates decision-makers' judgments into the metric. This local mission focus creates disparities among the MDI scores at different installations and influences the priority score,

increasing the difficulty to compare various types of infrastructure assets at different locations. The cost efficiency metric aligns with the Air Force established goals (Section 2.6.6) and accounts for energy usage and space utilization; however, these goals are incorporated in this one metric, which does not balance the goals to ensure that each goal will be achieved. Last, the service quality metric involves the same previously discussed issues (Section 2.6.5.1) as the commander adjustment metric (Equation (2)), which again results in inherent subjectivity. In the recently adopted priority equation, the opinion of decision-makers is captured in the local mission impact and service quality metrics, which accounts for 45 percent of the overall priority score. This inherent subjectivity built into the entire recently adopted priority equation (Equation (4)) from its infrastructure metrics once again diminishes its validity to objectively compare numerous infrastructure types at different locations and generate master priority lists for Air Force infrastructure assets.

2.6.6 Air Force Goals and Policies.

To align with the strategic vision of providing efficient, sustainable installations by using transformational business practices and innovative technologies, the Air Force established several goals and policies. This research effort focuses on the Air Force goals and policies associated with measureable metrics for maintenance and repair projects of existing infrastructure. Numerous Air Force directives and initiatives exist that do not prescribe specific targets to achieve; thus they are not incorporated into this research effort. The "20/20 by 2020" goal aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020 (Culver, 2007:6; Headquarters Air Force, 2009b:1). The Energy Independence and

Security Act (EISA) of 2007, which aims to reduce energy usage by 30 percent by the year 2015, Executive Order 13514, which aims to reduce potable water usage by 26 percent as well as non-potable water usage by 20 percent by the year 2020, and the "20/20 by 2020" goal are measureable targets that align with the Air Force strategic level vision (Congress of the United States, 2007:Section 431; Headquarters Air Force, 2009b:1; Obama, 2009:3). In order to achieve these goals, the Air Force is demolishing millions of square footage of infrastructure each year and is retrofitting facilities with energy efficient and water conserving elements. These goals intend to reduce the Air Force's real property footprint to an optimal size and to incorporate energy and water conservation methods in the interest of optimizing the performance of infrastructure assets that support the warfighting mission (Byers, 2010:3). Ultimately, the Air Force is reducing the stock of infrastructure assets as well as the maintenance and repair budget while maintaining a constant level of service and operations. This infrastructure challenge, specific to the Air Force, reinforces the requirement for a comprehensive framework for numerous infrastructure types to guide asset management decisions. "20/20 by 2020," EISA (2007), and Executive Order 13514 goals are specfic, measureable targets that align with the Air Force strategic level vision; however, the advancement of these goals is limited by available funding.

2.6.7 Air Force Budget(s).

Currently, the Air Force allocates 2.5 billion dollars annually to maintenance and repair projects (Department of Defense, 2010:11). This budget amounts to 0.95 percent of its CRV, which is significantly lower than the recommended industry standard of two to four percent (Vanier, 2001a:1-4). Additionally, all projects are subject to public

scrutiny, which requires expenditures to be accounted for and justified (Madaus, 2009:63-64). Although the Air Force does not pay personnel wages and labor costs from this operations and maintence budget, the money allocated for maintenance and repair is still significantly below the recommended industry standard. Allocating resources across asset types causes another budget issue for the Air Force. With limited resources available, decision-makers compare the worth and importance of infrastructure assets to determine which assets most require resource allocation. Alternatives require exploration due to budget constraints in order to manage assets from a holistic perspective and make the best decisions possible.

2.6.8 Air Force Alternative Selection.

Under the operations and maintenance budget, the Air Force examines five options for its infrastructure of demolish, maintain and repair, renovate, status quo, or construct an asset with capitalization (Department of Defense, 2001:3-4). Demolition disposes of obsolete assets or infrastructure with an extreme backlog. Maintenance and repair projects sustain infrastructure systems and execute deferred projects. Current regulations limit renovation upgrades to a 750 thousand dollar budget (Headquarters Air Force, 2009a:5-6). Status quo allows infrastructure to remain in its current condition. Capitalization, known as military construction (MILCON), constructs a new infrastructure asset that improves capability and corrects infrastructure issues above the 750 thousand dollar budgetary limit. MILCON within the DoD, however, falls under a separate budget with direct congressional oversight and approval; it does not compete with operations and maintenance funds. Decision-makers select among these five options

while taking into consideration information from the performance modeling tool, goals, policies, and budget to arrive at an optimal solution.

2.6.9 Air Force Operational Plan Development.

Once an optimal solution within the constraints is determined, operational plan development occurs. For example, if demolition is the most advantageous solution, efforts require terminating maintenance and repair projects on the asset and enacting measures to ensure resources are not wasted on this infrastructure (National Association of College and University Business Officers, 1995:22-28). If maintenance and repair is the preferred course of action, efforts require consideration for bundling projects together to gain time and cost efficiencies; projects can be performed on connected, neighboring infrastructure systems and parts can be replaced simultaneously (National Research Council, 1998:20-25). If renovation is the optimal solution, efforts require contemplation for completing backlog maintenance and repair projects in conjunction with the renovation in order to gain efficiencies. Along with addressing how the optimal solution affects current maintenance and repair projects, planning for future endeavors such as future maintenance and repair projects occurs as a part of operational plan development.

2.6.10 Air Force Execution.

In the case of the Air Force, execution involves coordinating the labor and funding to carry out the demolition, maintenance and repair project, and/or renovation. Typically, this plan is captured in a base's master plan (Department of Defense, 2001:3-6). Ultimately, execution implements the optimal solution to utilize limited resources in the most effective manner in order to optimize the performance of infrastructure assets.

2.6.11 Air Force Feedback.

Asset management for the Air Force is an iterative process that requires a feedback loop, as in the previously discussed models. The strategic vision, goals, and policies are in constant flux with the continual movement of headquarters staff personnel and commanders. Additionally, the operations and maintenance budget varies from year to year (Government Accountability Office, 2007:56). Thus, Air Force decision-makers examine results and address changes during feedback, prior to beginning the iterative process of asset management again.

2.7 Requirement for an Improved Air Force Performance Modeling Tool

This discussion of Air Force asset management components highlights the disconnect between the performance modeling tools (current and recently adopted) and the established goals, resulting in the requirement for an improved performance modeling tool that aligns with the strategic vision, goals, and policies of the Air Force. The primary limitation the Air Force encounters during alternative development is the discontinuity between the measureable metrics of the "20/20 by 2020," Energy Independence and Security Act (EISA) of 2007, and Executive Order 13514 goals and the infrastructure metrics of the performance modeling tools (Byers, 2010:3; Congress of the United States, 2007:Section 431; Culver, 2007:4-12; Headquarters Air Force, 2009b:1; Obama, 2009:3). The "20/20 by 2020" goal aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020, the EISA (2007) goal aims to reduce energy usage by 30 percent by the year 2015, and Executive Order 13514 aims to reduce potable water usage

by 26 percent as well as non-potable water usage by 20 percent by the year 2020; however, the current priority equation, Equation (2) (performance modeling tool), prioritizes projects with condition state and infrastructure inventory information based on each infrastructure's economic health and importance to operations (FCI and MDI) (Congress of the United States, 2007:Section 431; Headquarters Air Force, 2009b:1; Obama, 2009:3). This equation does not consider or account for the objectives of the "20/20 by 2020," EISA (2007), or Executive Order 13514 goals (reduction in square footage, energy usage, and water usage); it does not currently include energy, water, or square footage infrastructure metrics that the Air Force goals strive toward. Thus, the disconnect between the current performance modeling tool and goals results in decision-makers selecting an optimal solution based upon either the goals or the priority equation, but not both. This disconnect results in competing interests and a lack of synergy between the goals and current performance modeling tool. The lack of a cohesive focus between these two components affects the operational plan development and execution of demolition, renovation, and/or maintenance and repair projects; limited resources are not effectively utilized in a manner that aligns with the strategic vision or goals.

Additionally, the Air Force encounters a limitation with the recently adopted performance modeling tool during alternative development because this tool combines energy and space utilization goals into one infrastructure metric, cost efficiency, and does not include a water usage metric. Although the cost efficiency metric aligns with the established goals, it does not balance these goals to ensure that each goal is achieved. Thus, an improved performance modeling tool that incorporates energy, water, and space

utilization infrastructure metrics is necessary for the Air Force to objectively prioritize maintenance and repair projects across all major commands.

2.8 Literature Review Summary

Agencies such as the Air Force and the FHWA introduced the paradigm shift of asset management into their organizations for differing reasons. However, both agencies implemented asset management for the same desired outcome, to maximize limited resources and to optimize the performance of infrastructure assets (Culver, 2007:4-12; United States Department of Transportation, 1999:1-5). This chapter has discussed several asset management definitions as well as four current asset management models to provide a foundation for asset management, its concepts, and its present use. This foundation highlighted the requirement for a comprehensive asset management model that consists of various types of assets and that is generalizable to agencies with large, varying infrastructure sets and limited resources.

Additionally, this chapter has provided explanations of the prevalent, strategic components found in current asset management models and illustrated the relationships among these components. The components and relationships described represent critical entities to include in the strategic level asset management model for numerous infrastructure types. The example of the Air Force provided a real-world framework to explain these components and demonstrated how these components pertain to the Air Force. This example emphasized the requirement for an improved Air Force performance modeling tool that aligns with the organization’s strategic vision and goals to objectively prioritize maintenance and repair projects (Schofer et al., 2010:228-230).

3.0 Methodology – Part I

The literature review established requirements for both a comprehensive asset management model for numerous infrastructure types and an improved Air Force performance modeling tool. This chapter presents the methodology used to develop the strategic model and Chapter 4 presents the methodology used to develop the improved tool. The data modeling process, the methodology used to create the strategic asset management model for numerous infrastructure types, involves four phases. First, these phases are discussed, which include the development of the strategic asset management model. Next, the validation of this framework is discussed. The creation of a comprehensive asset management model fulfills the requirement that currently exists and develops a strategic framework that is generalizable to agencies with large, varying infrastructure inventories and limited resources.

3.1 Data Modeling Process

The method of data modeling is a type of systems modeling that defines and analyzes data requirements to support the business practices of an agency (Batini, Lenzerinim, and Navathe, 1986:334-342). Specifically, "a data model is a set of constructs for representing objects and processes in digital form" (Longley, Goodchild, Maguire, and Rhind, 2005:178-179). A data model also involves ontologies, which define the components of a system and associate them in classes, relationships, or functions (Gruber, 2005:1-2). The purpose of the model, type of analysis required, and information available strongly influence the type of data model that is utilized (Halfawy

and Froese, 2007:441-445). Data modeling consists of four levels (listed in order of increasing abstraction): reality, conceptual model, logical model, and physical model (Longley et al., 2005:178-179). The data modeling process is presented in Figure 5.

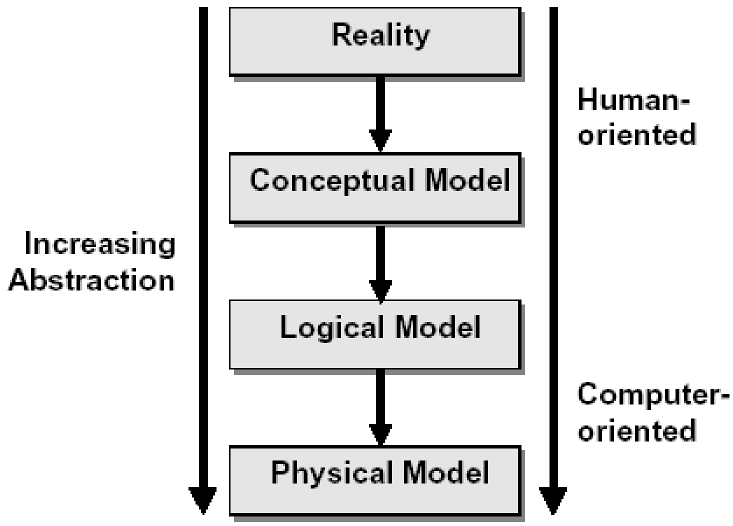

Figure 5. Data Modeling Process (Longley et al., 2005:178-179)

This particular method appropriately lends itself to the research project due to its ability to model data in a standard, consistent, and predictable manner (Sen and Sinha, 2005:79-80). Data modeling is particularly applicable to projects that require management of data as a resource, integration of information systems, and modification of databases for organizational operations (Whitten, Bentley, and Dittman, 2004:222-253). Specifically for the scope of this research project, data modeling focuses on asset management processes for agencies with large, varying infrastructure sets and the data required to make decisions based upon the strategic components of these infrastructure systems. The result of this data modeling process, in the context of the Air Force, will align with the Next Generation Information Technology Program Management Plan

objective to streamline the required data and its transparency. The strategic asset management model for numerous infrastructure types will progress through the four levels of the data modeling process in order to develop a framework for asset management. This model will then be analyzed and validated using a representative sample of Air Force infrastructure. The specific data modeling process for this research project is presented in Figure 6.

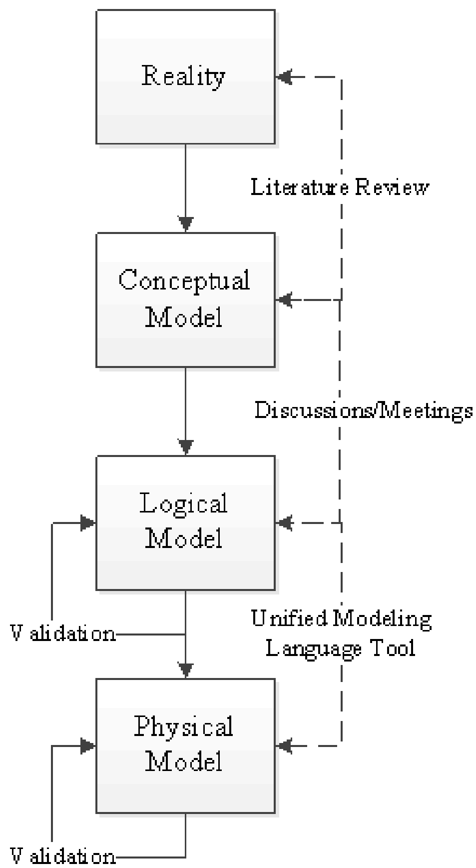

Figure 6. Data Modeling Process Specific to Research Project (modified from Longley et al., 2005:178-179)

3.1.1 Phase I – Reality.

The first of the four major phases in developing a working data model of a system is investigating reality, which consists of real-world phenomena (Longley et al.,

2005:178-179). Investigating reality establishes an understanding of the systems and the interactions of its components (Sitzabee et al., 2009b:291). It also includes the aspects that are deemed applicable to the real-world construct. Last, this investigation provides the real-world knowledge basis for the remaining phases of data modeling.

This phase entailed establishing a thorough understanding of the process of asset management and its components. A literature review created a foundation of knowledge for infrastructure systems as well as the interactions among components within the system. Additionally, the literature review encompassed the emergence of asset management, the current research, and established industry practices as well as established Air Force practices to gain a working knowledge of both processes of asset management. This method facilitated a comprehension of concepts applicable to the real-world construct of asset management as well as Air Force specific asset management business practices, which allowed the components of asset management to be fully grasped.

3.1.2 Phase II – Conceptual Model.

The second phase is the creation of the conceptual model (Longley et al., 2005:178-179). This model is oriented toward its human users and is composed of selected objects and processes that are relevant to the problem domain (Sitzabee et al., 2009b:291). Typically, a conceptual model is an outline of concepts and their relationships (Whitten et al., 2004:313-367). It identifies objects of significance, collects information, and describes associations between components. In essence, a conceptual model organizes the entities, attributes, and relationships of a system (Whitten et al.,

2004:313-367). The conceptual model provides the foundation for the progression to logical model development.

This phase required defining the set of asset management concepts and the problem domain applicable to agencies with a large, varying infrastructure inventory and limited resources, such as the Air Force infrastructure system. Definitions of each component in the asset management process conceptualized and operationalized objects of significance from reality. Identifying information and characteristics were collected for these components along with their entities and attributes through informal, conversational meetings focused on asset management. The analysis of each meeting consisted of seven stages: thematizing, designing, meeting, transcribing, analyzing, verifying, and reporting (Kvale and Brinkmann, 2009:19-20 & 102). This seven stage process is presented in Figure 7.

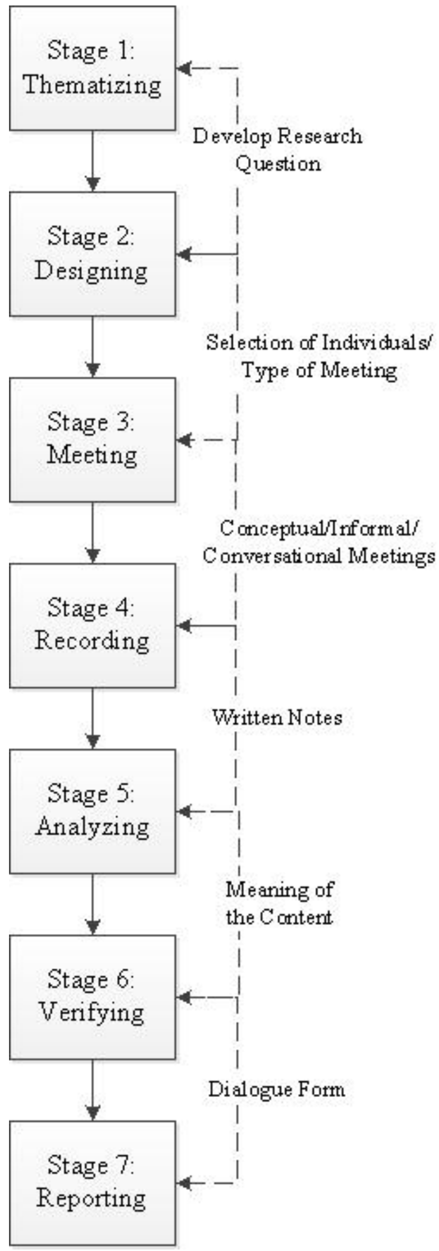

Figure 7. Meeting Analysis Process Specific to Research Project (modified from Kvale and Brinkmann, 2009:20)

Formulation of the research question completed the first stage, thematization (Kvale and Brinkmann, 2009:19-20). Selection of the individuals and type of meeting encompassed the design portion (stage 2) (Kvale and Brinkmann, 2009:147-151). The particular individuals selected for this research project represented a sampling of

individuals involved in all vertical levels of the Air Force asset management process, Headquarters Air Force (Air Force Asset Management and Operations Office), a major command (Air Force Material Command), and a squadron (Wright-Patterson Air Force Base) as well as research entities involved with Air Force asset management, graduate and continuing education (Air Force Civil Engineer School and Air Force Institute of Technology). These meetings (stage 3) provided a thorough understanding from experts of the asset management system and the relationships between components. The design consisted of informal, conversational meetings in order to gain insight and clarification of the concepts of asset management as well as provide an open and adaptable environment conducive to the individual's background, preferences, and priorities (Patton, 2002:342-344).

During the meetings, meeting minutes (stage 4) in the form of written notes occurred to capture as well as document topics, key points, and themes discussed. This interpretive process transferred oral speech to written notes and prepared the information for analysis (Kvale and Brinkmann, 2009:177-180). Analysis (stage 5) of these meetings focused on determining the meaning of the content including the key points, definitions, themes, and novel perspectives (Kvale and Brinkmann, 2009:196-197). Meeting with several experts in the asset management field ensured peer validation (stage 6) of the information and a consensus among individuals, resulting in reliable and generalizable findings (Kvale and Brinkmann, 2009:255). Last, this research project communicated and reported (stage 7) the findings of these meetings through this thesis endeavor (Kvale and Brinkmann, 2009:275-280 & 285). The components, their entities, and attributes

were outlined to understand their relationships and interactions. Once these concepts and objects were outlined, the third phase of data modeling began.

3.1.3 Phase III - Logical Model.

<u>3.1.3.1 Logical Model Development.</u>

The third major phase to developing a working data model of a system is the logical model (Longley et al., 2005:178-179). A logical model is an implementation-oriented representation of reality and is depicted in diagrams and lists (Silverston, 2005:340-342). It defines ontologies and associations from the conceptual model (phase II of data modeling). A logical data model also depicts the entities, attributes, and relationships among the components of a system. Additionally, this data model promotes analysis of the system by decision-makers. The development of a logical model includes illustrating influential strategic components as well as matching organizational functions with the specific data required to support each function (Longley et al., 2005:178-179; Silverston, 2005:340-342). This type of model assists agencies in creating a common understanding of asset management business processes, data requirements, and maintenance and repair requirements across both vertical and horizontal boundaries.

The logical model phase encompassed developing a logical model using Microsoft Visio, a commercial diagramming tool, that is applicable to agencies with large, varying infrastructure sets and limited resources, such as the Air Force. Phase III produced a graphical diagram that represents a logical data model of the asset management process. This logical model defined ontologies for the asset management process as well as their associations. It also included a depiction of the strategic components required for the asset management process. Last, it illustrated the

relationships among an agency's functions, the strategic components, and the data requirements to promote analysis of the system. Once the logical model was developed, validation of the logical model occurred.

3.1.3.2 Logical Model Validation.

Validation demonstrated the utility of this particular asset management model for large, varying infrastructure sets. A model that was validated using the Air Force has far reaching applicability and generalizability to organizations with comparable infrastructure systems and limited resources because the Air Force, an agency with a large, varying infrastructure inventory, a limited budget, infrastructure challenges, and extensive infrastructure operations, is comparable to large corporations, public agencies, and universities with similar infrastructure characteristics and budget constraints. Thus, a representative sample of Air Force infrastructure was used to validate this logical model.

A second round of asset management meetings was conducted in the same manner as depicted in Figure 7. During these meetings, each component and its relationships were explained as it pertains to the Air Force. Similar to the previous meetings, these meetings also consisted of seven stages (Kvale and Brinkmann, 2009:19-20 & 102). The overarching research question (thematizing, stage 1) was developed and the type and individuals (designing, stage 2) were selected for the entire research endeavor when the first round of meetings was conducted. The particular individuals remained the same in order to allow the researcher to utilize the constant comparison method, which compares newly collected data with previously collected data to solidify an understanding of concepts. These knowledgeable experts also maintained expertise about Air Force asset management and familiarity with the aims of this project. The

design again consisted of informal, conversational meetings in order to provide an environment conducive to constructive criticism of the model and confirm the applicability of the logical model to the Air Force (Patton, 2002:342-344).

During the meetings (stage 3), the researchers recorded meeting minutes (stage 4) in the form of written notes to capture as well as document topics, key points, and themes discussed. Analysis (stage 5) of these meetings focused on determining the meaning of the content (Kvale and Brinkmann, 2009:196-197). This model was validated and vetted (stage 6) through peer validation, involving discussions with experts in Air Force asset management offices and research entities. This research project communicated and reported (stage 7) the findings from the second round of meetings in the exact manner as the first round of meetings (Kvale and Brinkmann, 2009:275-280 & 285). Additionally, this model and the meetings highlighted any discontinuities between the strategic components in the Air Force asset management process. The purpose of this logical model validation was to establish its usability for the Air Force in order to extend the model to any agency with a similar infrastructure set and budget constraints.

3.1.4 Phase IV – Physical Model.

3.1.4.1 Physical Model Development.

The fourth phase is the creation of the physical model and is the final step in developing a data model (Longley et al., 2005:178-179). A physical model is computer-oriented, portrays the actual implementation, and demonstrates how objects are digitally implemented (Sitzabee et al., 2009b:291-292). It describes the databases used to store data and identifies the data required for the process (Longley et al., 2005:178-179). A physical model defines key relationships among object types and databases as well as

details the precise operations to be performed (Connolly and Begg, 2005:494-518). Furthermore, it is usually comprised of tables in relational database software and details the way components are employed across the system. This type of model assists agencies in achieving efficient access to data across the enterprise as well as integrity of data and security measures (Connolly and Begg, 2005:494-518). It also produces the tactical level data for analysis in order to provide decision-makers with the appropriate information to develop viable approaches and alternatives.

The physical model phase involved creating an example implementation for the Air Force of ontologies using Enterprise Architect, a unified modeling language tool, that applies specifically to agencies with large, varying infrastructure inventories and limited resources, such as the Air Force. Phase IV visualized, constructed, and specified the data requirements for an example of an infrastructure metric that contributes to one component of the system. This research effort created an example implementation due to the lack of compatibility between the strategic level MMS and tactical level MMS. The implementation of a fully developed physical model for the Air Force requires the development of an enterprise level MMS. This physical model example defined the data required for this component of the asset management process and visually represented its digital implementation. It also included links between data for this particular infrastructure metric. Additionally, it completed the four phases of the data modeling process and promoted analysis of the system. Once the example physical model implementation was developed, validation of this example occurred.

3.1.4.2 Physical Model Validation.

The physical model validation was essentially identical to the logical model validation, because the system and its components remained constant. A representative sample of Air Force infrastructure was again used to validate the example implementation of the physical model due to its large, varying infrastructure set and limited budget. A third round of meetings was conducted in the same manner as the first and second rounds (stages 1 to 5) and also followed the same seven stages as illustrated in Figure 7. This model was again validated and vetted (stage 6) through peer validation, encompassing discussions with the same Air Force asset management experts. During these asset management meetings, the components, relationships, and data linkages were explained. The entities and associations were examined and discussed as they pertain to the Air Force. The design (stage 2), meetings (stage 3), recordings (stage 4), analysis (stage 5), verification (stage 6), and reporting (stage 7) occurred in the exact manner for the physical model validation as they did for the logical model validation. Additionally, this model and the meetings again highlighted any discontinuities between the strategic components of the Air Force's asset management process. The purpose of this physical model validation, similar to the logical model validation, was to establish the usefulness of the example implementation for the Air Force in order to generalize the model to any agency with a large, varying infrastructure set and limited resources.

4 .0 Methodology – Part II

This chapter presents the methodology used to create the improved performance modeling tool, which is one component of the strategic asset management model for numerous infrastructure types. The creation of an improved performance modeling tool fulfills the requirement that currently exists and allows this newly developed tool to align with the Air Force strategic vision, goals, and policies. First, the improper linear modeling process is discussed along with the improved performance modeling tool development. Next, the verification of the improved performance modeling tool is discussed.

4.1 Improper Linear Modeling Process

A long standing controversy exists between utilizing experts' informal judgments and prediction models that utilize statistics, such as linear regression models (Grove, 2005:1233-1234). The statistical approach creates an objective prediction model that integrates data and information to predict a criterion. The approach that uses experts' informal judgments relies upon their opinions and expertise. The research that compares these two approaches concludes that objective prediction models are superior to the opinions of experts when using codable input variables (Dawes, 1979:573). The superiority of statistical prediction models stems from their consistency and objectivity; however, data dictates the feasibility of an objective prediction model. For instance, researchers are not able to use statistics to create a prediction model when a measurable criterion variable does not exist. In these situations, a method that combines these two

approaches to draw from the advantages of both the objective prediction model and experts' judgments is utilized; the improper linear modeling process is the method that aggregates the statistical approach and the approach that uses experts' judgments to develop a prediction model. The improper linear modeling process utilizes a more objective approach than the opinions of experts when the data does not support a purely statistical analysis.

The method of improper linear modeling utilizes experts' judgments and data to formulate a linear equation that calculates an outcome (Dawes, 1979:572). This process allows experts to select the independent variables in the same manner as independent variables are selected for linear regression. The selection of variables involves forward selection or testing each variable one by one to determine its statistical significance. Those variables that possess statistical significance are included as independent variables in the linear model. However, experts utilize their experience and expertise to weight these variables, instead of using statistics to calculate the coefficients of the independent variables. The independent variables and their weights build a linear function in order to predict the value of an outcome (Dawes, 1979:572). This linear function determines the best relationship between the independent variables and a dependent variable based upon experts' judgments and infrastructure data (Dawes and Corrigan, 1974:97). The indepdendent variables and weights determined by the method of improper linear modeling calculate an outcome using a modified version of the standard linear regression model equation, which is presented in Equation (5) (Field, 2009:198-199 & 790). Y is the dependent variable and outcome. X_i is the indepdendent variable input and w_i is the weight given to each independent variable.

$$Y = w_1X_1 + w_2X_2 + \dots + w_nX_n \quad (5)$$

The improper linear modeling process typically consists of several steps including initial examination of independent variables, selection of independent variables, model development, and model verification (Dawes, 1979:573-575).

This particular method lends itself to this research project due to its ability to develop a linear function from measureable infrastructure metrics, assign weights to these metrics, and leverage the knowledge of experts in the asset management field to determine a priority order for maintenance and repair projects (Bowman, 1963:312-315; Goldberg, 1970:425-427; Grove, 2005:1233-1234). A criterion does not exist for the priority order of maintenance and repair projects because the priority of a project is not a measured data point. Thus, the improper linear modeling process develops a linear equation for comparative analysis that rank orders the priority of projects to predict an outcome from infrastructure data and experts' judgments as opposed to linear regression, which develops a linear equation to predict a measured criterion.

The improper linear modeling process is utilized to improve upon the current performance modeling tool (Equation (2)) and the recently adopted performance modeling tool (Equation (4)). Specifically, experts' judgments and data are utilized to select the independent variables to include in the improved performance model. This process is identical to the selection process of independent variables for linear regression models. Each selected independent variable is a codable, measurable value. Instead of statistical analysis determining the coefficients of each independent variable, the weights are determined by asset management experts. This information formulates a linear model that predicts the priority order of maintenance and repair projects. Decision-makers can

utilize this prediction model to objectively prioritize maintenance and repair projects in order to distribute limited funds to assets that most require resource allocation. The scope of this research project focuses on incorporating measureable infrastructure metrics associated with the maintenance and repair of existing infrastructure that tie directly to the Air Force's established goals and policies, specifically energy, water, and space utilization metrics as well as minimizing subjectivity to develop an improved Air Force performance modeling tool. This improved performance modeling tool was then thoroughly analyzed and verified. The specific improper linear modeling process for this research project is presented in Figure 8.

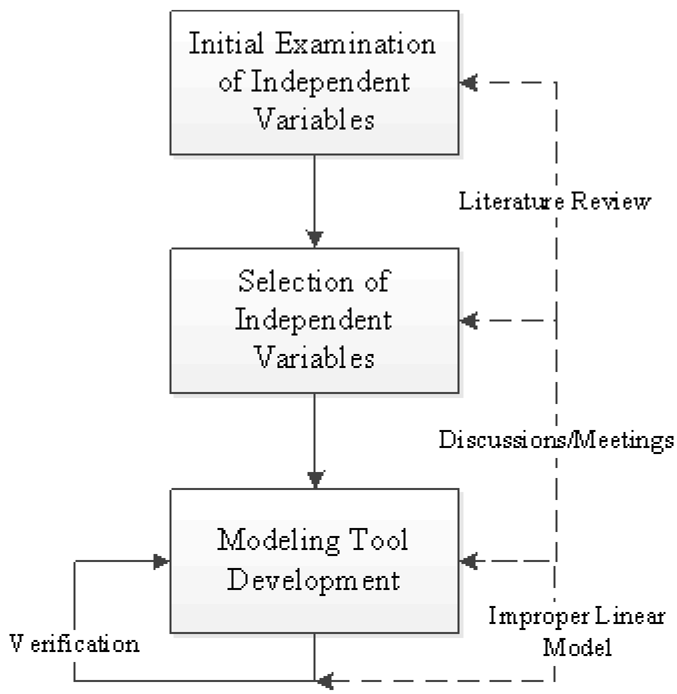

Figure 8. Improper Linear Modeling Process Specific to Research Project (modified from Schultz, White, and Ducklow 2003:136-137)

4.1.1 Initial Examination of Independent Variables for an Improved Air Force Performance Modeling Tool.

The first step in the improper linear modeling process is an initial examination of independent variables (Dawes, 1979:573-575). This step provided an understanding of the possible independent variables and how they are measured or calculated (Cook, 1977:15-18). An examination of their relationships occurred during this step as well to determine the effects resulting from the connections between independent variables (Cook, 1979:169-172). This initial examination of independent variables provided a knowledge basis for selecting the independent variables that will be included in the improved performance modeling tool.

This step entailed establishing a comprehensive understanding of independent variables included in the current and recently adopted performance modeling tools (the priority equations for maintenance and repair projects) to encompass the measurements, calculations, and relationships of these infrastructure metrics. The infrastructure inventory (Sections 2.5.2 and 2.6.2), condition state (Sections 2.5.3 and 2.6.3), importance and criticality (Sections 2.5.4 and 2.6.4), and performance modeling (Sections 2.5.5 and 2.6.5) portions of the literature review provided the knowledge basis for the improved performance modeling tool. Additionally, the literature review encompassed the advantages and disadvantages of the infrastructure metrics of the current and recently adopted tools. These methods provided a thorough understanding of how the Air Force currently prioritizes maintenance and repair projects and allowed the second step in the improper linear modeling process to begin.

4.1.2 Selection of Independent Variables for an Improved Air Force Performance Modeling Tool.

The second step is the selection of independent variables (Dawes, 1979:573-575). Prior to choosing the independent variables to include in the improved performance modeling tool, the purpose and goals of the modeling tool were established (George, 2000:1304-1308). These objectives provided selection criteria for the independent variables and a specific target for the dependent variable. This step required aligning the purpose of the improved performance modeling tool with the strategic vision, goals, and policies of the Air Force. From this objective, the specific selection criteria required the independent variables to account for the measureable metrics and specific targets of Air Force goals and policies, such as "20/20 by 2020," Energy Independence and Security Act (EISA) of 2007, and Executive Order 13514 goals (space utilization, energy usage, and water usage), as well as industry and Air Force infrastructure standards of facility condition and mission dependency (Congress of the United States, 2007:Section 431; Headquarters Air Force, 2009b:1; Obama, 2009:3).

A fourth round of meetings was conducted in the same manner as the first three rounds, also consisting of seven stages as depicted in Figure 7; however, this round of meetings began at stage three, because stages one and two remained constant throughout the research project. During these meetings (stage 3), the improper linear modeling process was explained. The recordings (stage 4), analysis (stage 5), and reporting (stage 7) occurred in the exact manner as they did for the logical and physical model validations. These meetings confirmed through peer validation (stage 6) that the selection of independent variables accurately reflected the strategic vision, goals, and

policies of the Air Force and accounted for them with measureable infrastructure metrics. These meetings identified and selected the independent variables to include in the improved tool. The selection of independent variables provides the foundation for the improved performance modeling tool development.

4.1.3 Improved Air Force Performance Modeling Tool Development.

The third step to improving the current performance modeling tool is development of the modeling tool (Dawes, 1979:573-575). The selected variables from step two produce a linear function or improper linear model. The development step assigned weights to these independent variables, so that the improper linear model consists of independent variables, each multiplied by a weight and then added together (Goldberger, 1962:369-375). Infrastructure maintenance and repair projects from the Air Force Real Property database were examined to determine the appropriate weights for each independent variable. The weights should require decision-makers to consider each independent variable and its adjustment of the overall priority score, but also allow the predominant independent variables, defined by experts, to account for a larger portion of the priority score. Asset management experts determined the weights for each independent variable in the fourth round of meetings.

Additionally, an improper linear model must fulfill two criteria: the weights sum to 100 percent and the boundary conditions are maintained at the minimum and maximum of the defined scale. During development of the improved tool, the sum of the weights and boundary conditions were examined to ensure they satisfied the criteria for an improper linear model. Once the improved modeling tool was fully developed, verification of the tool occurred.

4.1.4 Improved Air Force Performance Modeling Tool Verification.

The fourth step is verification of the model and is the final step in developing an improper linear model (Dawes, 1979:573-575). Verification of the model confirms its utility and the model's ability to generate an outcome given a set of data. This improper linear model or improved performance modeling tool was verified with asset management experts, who discussed, compared, and analyzed the advantages and disadvantages of the infrastructure metrics as well as priority orders produced by the current, recently adopted, and improved performance modeling tools. Additionally, the strategic level asset management model developed for numerous infrastructure types evaluated the current, recently adopted, and improved performance modeling tools to determine which tool best aligns with the framework of the strategic model and reflects the components of asset management.

A fifth round of meetings with asset management experts was conducted in the same manner as the first four rounds and also began at stage three of the meeting analysis process. During these informal, conversational meetings (stage 3), the three priority equations, their infrastructure metrics, and the priority orders that resulted from each equation were explained. The recordings (stage 4), analysis (stage 5), verification (stage 6), and reporting (stage 7) occurred in the exact manner as they had previously. These meetings confirmed through peer validation that the improved performance modeling tool accurately reflected and accounted for the strategic vision, goals, and policies of the Air Force as opposed to the current and recently adopted performance modeling tools. The meeting also confirmed through peer validation that the improved performance modeling tool considers the components of asset management and aligns with the framework

created by the strategic model for numerous types of infrastructure assets as opposed to the current and recently adopted performance modeling tools. The purpose of this verification was to establish the usefulness of the improved performance modeling tool for the Air Force in order to confirm that applicability of this tool to Air Force's large, varying infrastructure inventory; and ultimately objectively prioritize maintenance and repair projects across various types of infrastructure assets at different locations.

5.0 Results – Part I

This chapter presents the results of the data modeling process. The outcomes from this process strive to accomplish the objectives set forth for this research project; the results provide conclusions and key findings that are vital to the research endeavor and contribute to the asset management body of knowledge. First, the strategic level asset management model is introduced and the analysis of this model is discussed for agencies with a large, varying infrastructure set and limited resources. Next, the validation of this model, using a representative sample of Air Force infrastructure, is discussed and analyzed in order to confirm the usability of the strategic models for agencies with similar infrastructure characteristics and budget constraints.

5.1 Data Modeling Process

The results from each of the four levels (reality, conceptual model, logical model, and physical model) of data modeling are presented.

5.1.1 Phase I – Reality.

This phase entailed an investigation of reality and its real-world phenomena. As previously stated in Section 3.1.1, the literature review established an understanding of the asset management process and the relationships among its strategic components. It also provided a working knowledge of the concepts of asset management as well as its established business practices. Additionally, the investigation of reality considered the six requirements (no more redundant data entry, high-tech data collection, simplified data calls, on-site supply orders, automated real property installed equipment requirements,

and total cost information in one place) of Next Generation Information Technology (IT), discussed in Section 2.6.2, in order to examine the criticality of transparent data at all vertical levels and the importance of streamlined data collection and maintenance. Thus, the reality phase allowed the real-world construct of asset management to be fully comprehended.

5.1.2 Phase II – Conceptual Model.

The creation of the conceptual model involved executing the seven stages (thematizing, describing, meeting, transcribing, analyzing, verifying, and reporting) that were illustrated in Figure 7. Thematization (stage 1) encompassed formulation of the research question, which was presented in Chapter 1. The design stage (stage 2), discussed in Chapter 3, consisted of selecting a sample of individuals that represented all vertical entities engaged in the Air Force asset management process as well as organizing and conducting informal, conversational meetings (stage 3). Meeting minutes (stage 4) from the meeting occurrence are documented in the form of notes and located in Appendix A; the analysis (stage 5) from these notes and verification (stage 6) of the results, ensured by peer validation from the asset management experts is discussed in the following paragraphs. Last, the thesis document communicates and reports (stage 7) these seven stages and their results.

The analysis reinforces the two requirements that this research project aims to fulfill:

- A strategic asset management model that creates a decision-making framework, guides the analytical process of asset management, and addresses infrastructure challenges for agencies with a large, varying infrastructure inventory and limited resources

- An improved performance modeling tool that consists of measureable infrastructure metrics that align with the strategic vision, goals, and policies of the Air Force to objectively prioritize maintenance and repair projects for various types of infrastructure assets at different installation locations

The synthesis of the information from this meeting highlights two key findings for the Air Force asset management process.

First, a discontinuity exists between the established strategic vision, goals, and policies and the current as well as recently adopted performance modeling tools. Hence, decisions regarding maintenance and repair of infrastructure do not reflect or account for the strategic vision, goals, and policies of the Air Force. For example, the "20/20 by 2020" goal aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020, the Energy Independence and Security Act (EISA) of 2007 goal aims to reduce energy usage by 30 percent by the year 2015, and Executive Order 13514 aims to reduce potable water usage by 26 percent as well as non-potable water usage by 20 percent by the year 2020; however, the current equation (current performance modeling tool) that prioritizes maintenance and repair projects does not account for energy usage, water usage, or space utilization (Congress of the United States, 2007:Section 431; Headquarters Air Force, 2009b:1; Obama, 2009:3). Additionally, the recently adopted performance modeling tool combines the energy and space utilization goals into one infrastructure metric, which does not balance these goals to ensure that each goal is achieved; it also does not account for water usage.

Second, the data and maintenance management system (MMS) required for strategic level asset management do not align with the data and MMS required for tactical

level asset management. The strategic level forecasts, requests, and justifies a long-term budget for demolition, renovation, capitalization, and maintenance and repair projects with a 10 to 12 year outlook; however, the tactical level allocates the operations and maintenance budget and advocates for short-term requirements with a one to two year outlook. Additionally, the MMS utilized by the strategic level is not necessarily the same MMS utilized by the tactical level. Thus, the lack of compatibility and proper communication hinders the flow of data as well as the top-down, bottom-up approach that enables decision-makers to formulate viable courses of action. Ideally, the approaches and alternatives conceived by the decision-makers are in the best interest of all vertical levels (tactical, operational, and strategic) of the Air Force.

Chapter 7 expands upon the two key findings and the conclusions that result from these findings. Overall, the conceptual model phase enabled the conceptualization and operationalization of each component in the asset management process as well as an understanding of the problem domain for agencies with a large, varying infrastructure inventory and limited resources.

5.1.3 Phase III – Logical Model.

<u>5.1.3.1 Logical Model Development.</u>

Development of the logical asset management model produced a strategic level model of an operational infrastructure system with numerous types of assets. This logical model consists of components, defined and described in Section 2.5, that are prevalent in the business practices of asset management. Figure 9 presents the logical model and graphically depicts influential strategic components as well as their relationships that are vital to the asset management process. It also illustrates ontologies and associations

among the asset management components and identifies the data required to promote analysis of infrastructure operations.

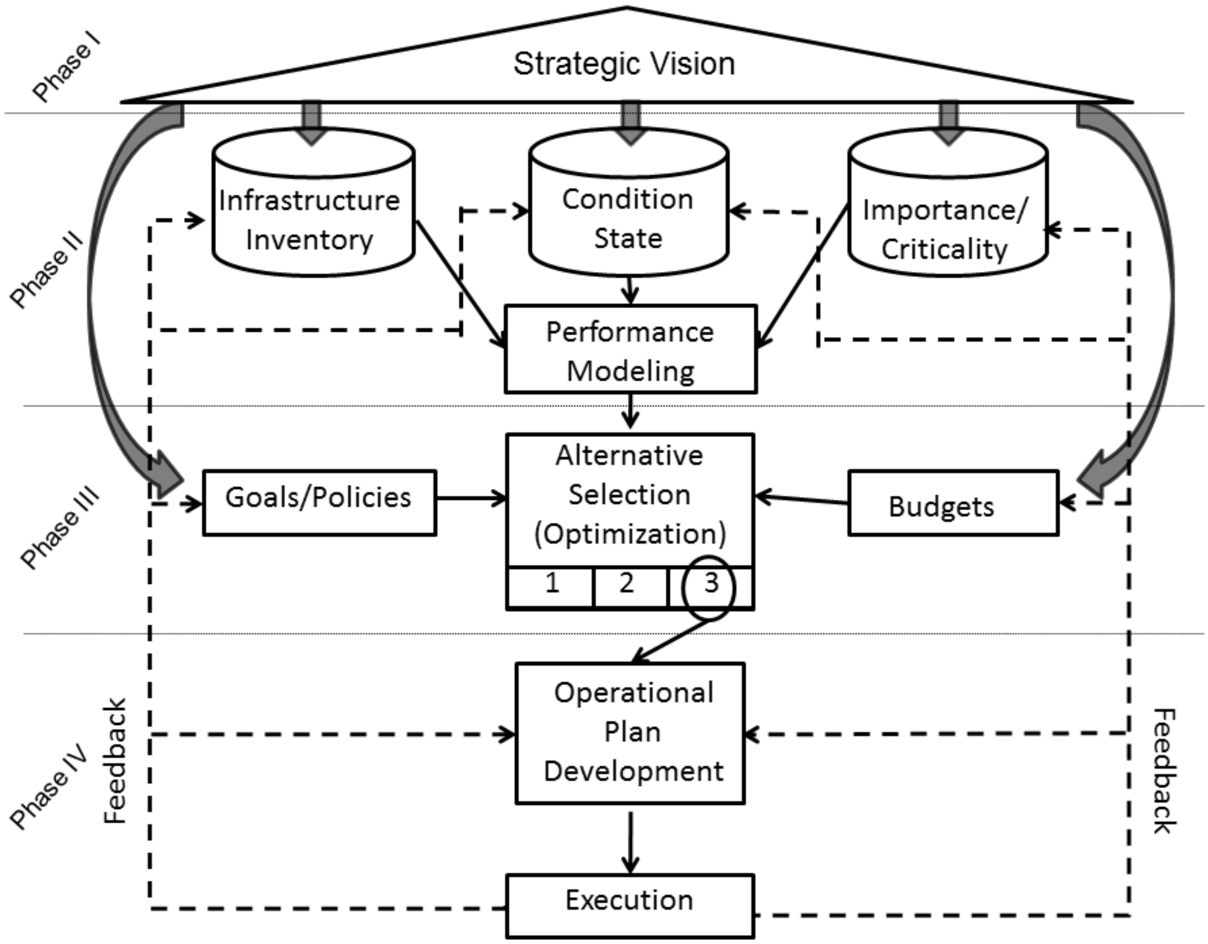

Figure 9. Logical Asset Management Model

The logical asset management model presented in Figure 9 creates a comprehensive framework that provides guidance for the asset management process. It serves as a useful, decision-making tool that is applicable to agencies with a large, varying infrastructure inventory and limited resources. This model enables decision-makers to formulate viable approaches and alternatives to infrastructure management and

facilitates efficient use of the annual operations and maintenance budget in order to optimize the performance of infrastructure assets.

5.1.3.2 Logical Model Validation.

Validation of the logical asset management model verified the usability and utility of this model for agencies with large, varying infrastructure sets and limited resources. The validation used a representative sample of Air Force infrastructure to tailor the general logical model specifically to the Air Force's infrastructure operations. Figure 10 presents the logical model validation, which modifies the general logical model to the Air Force's asset management process, depicts the components as they pertain to this specific organization, and identifies the data required for analysis of its infrastructure systems with numerous types of assets. It also illustrates the importance of transparent data as well as streamlined data collection and maintenance, which the six requirements of Next Generation IT aim to achieve for the Air Force.

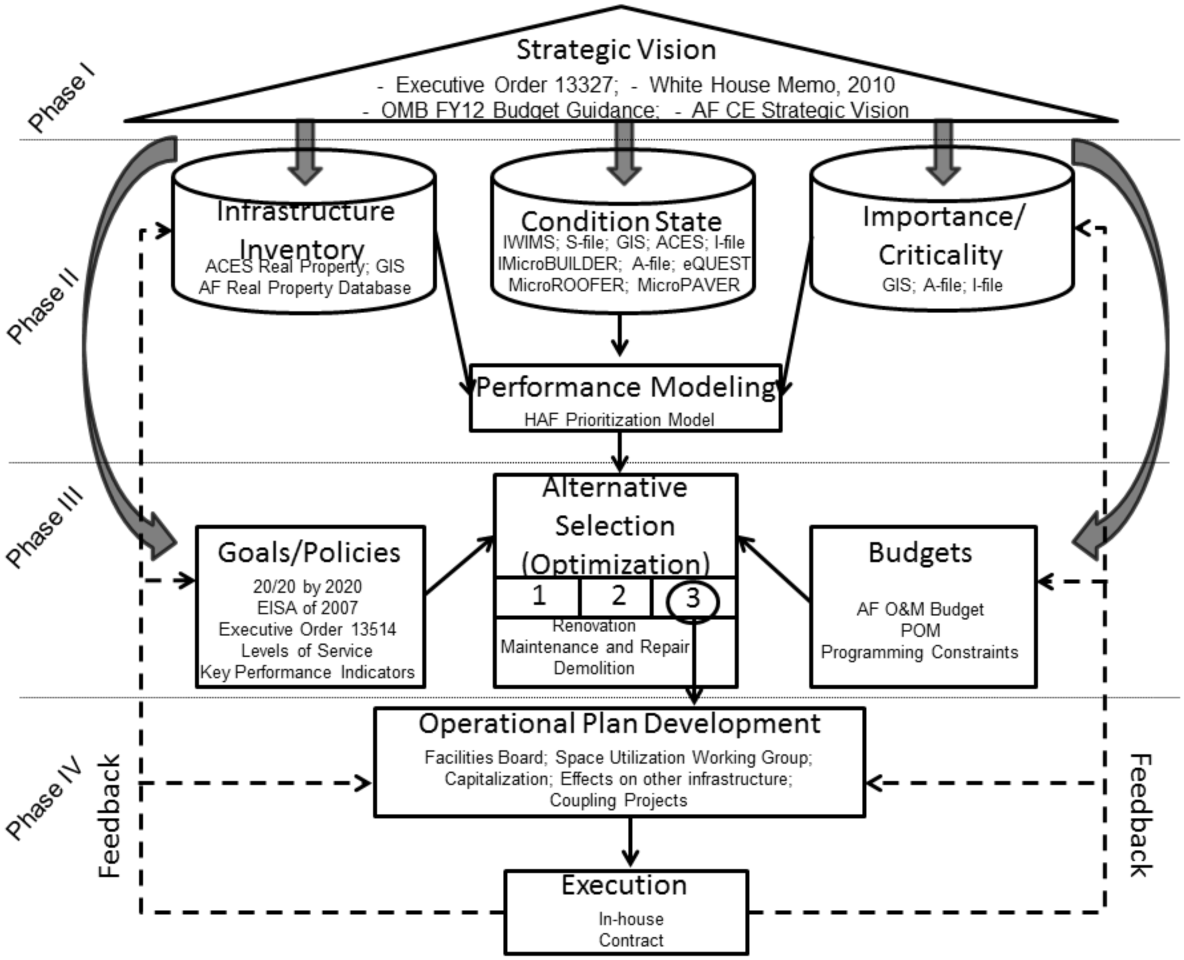

Figure 10. Logical Air Force Asset Management Model

The validation of the logical model also involved executing the seven stages (thematizing, describing, meeting, transcribing, analyzing, verifying, and reporting) that were illustrated in Figure 7. The thematization (stage 1), design (stage 2), and meeting (stage 3) stages of the informal, conversational meetings remained consistent with the conceptual model phase. The discussions with experts from Air Force asset management offices and research entities that transpired during these meetings are documented in the form of meeting minutes (stage 4), which are located in Appendix B; the analysis (stage 5) and verification (stage 6) of the logical model are discussed in the following

paragraphs. Last, this research project communicates and reports (stage 7) these seven stages and their results.

Verification of the results validated and vetted the Air Force logical asset management model. The analysis highlights and emphasizes one of the key findings from the conceptual model phase, specifically that a discontinuity exists between the Air Force's established strategic vision, goals, and policies and its current performance modeling tool. The disconnect between these components results in decision-makers selecting an optimal solution based upon either the strategic vision, goals, and policies or the priority equation, but not both. These competing interests created by this disconnect lack synergy and cohesiveness. Additionally, a similar disconnect exists between the established strategic vision, goals, and policies and the recently adopted performance modeling tool. The discontinuity causes decision-makers to select an optimal solution based upon achieving one of the goals, but not necessarily all of the goals. The improved performance modeling tool, presented in Chapter 6, aims to eliminate these discontinuities as well as fulfill the requirement for a tool that consists of infrastructure metrics that align with the strategic vision, goals, and policies of the Air Force to objectively prioritize maintenance and repair projects across various types of infrastructure assets. Chapter 7 expands upon this key finding as well as the conclusions drawn from the improved performance modeling tool.

The logical Air Force asset management model, presented in Figure 10, creates a decision-making framework for the Air Force that guides the analytical process of asset management and addresses infrastructure challenges, specifically for this organization. The validation of this comprehensive model confirms its generalizability to agencies with

a large, varying infrastructure inventory and limited resources. It also affirms that agencies are able to tailor the general logical model to infrastructure systems of a particular organization, which establishes the model's usability and utility for agencies with similar infrastructure characteristics and budget constraints.

5.1.4 Phase IV – Physical Model.

5.1.4.1 Physical Model Development.

Development of the physical model produced a strategic level framework that establishes an example implementation of an infrastructure metric that contributes to one component of the system of the asset management process with numerous types of infrastructure assets. This physical model specifies the required data for this particular metric as well as the links between data. It also produces an Extensible Markup Language (XML) file from the example digital model implementation, which populates a database with data (Connolly and Begg, 2005:509-516). This XML file functions with various database formats to structure, store, and transport the data required for the asset management process.

5.1.4.2 Physical Model Example.

Data requirements and performance modeling tools are specific to the infrastructure operations of individual agencies. Data requirements are tailored to one infrastructure metric from the Air Force performance modeling tool to provide an example that utilizes Enterprise Architect and demonstrates how a physical asset management model operates. The implementation of a fully developed physical model for the Air Force requires the development of an enterprise level MMS. Currently, the data and MMS required for strategic level asset management do not align with the data

and MMS required for tactical level asset management. Implementation of a fully developed physical model for the Air Force with the present MMS structure of the organization would result in data incompatibilities amongst the various vertical levels. Thus, Figure 11 presents an example of the data schema of the Air Force physical model, which illustrates an example of the tables and data requirements to collect and maintain for an infrastructure metric for the Air Force asset management process that considers Next Generation IT. The data identified in the performance modeling tables represent the necessary data for one infrastructure metric of the improved priority equation in order to employ this piece of the improved tool, make decisions based upon the strategic components, and promote analysis of infrastructure systems; the results and conclusions for the improved performance modeling tool are discussed in Chapter 6.

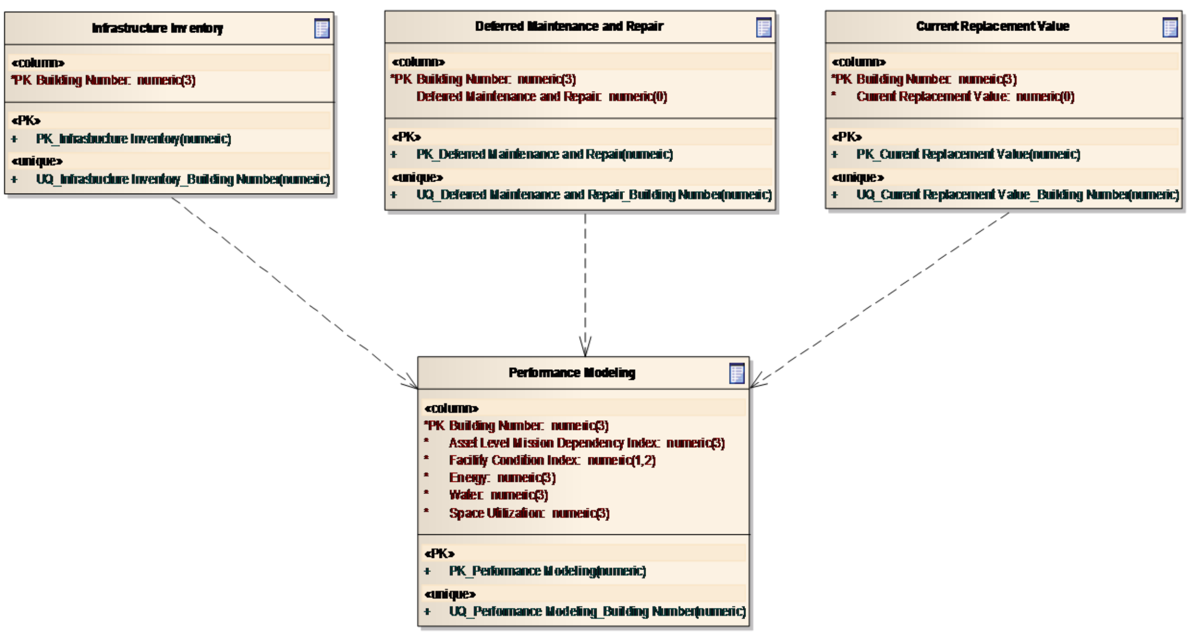

Figure 11. Data Schema of the Air Force Physical Asset Management Model

The calculation and data required to determine a facility condition index (FCI) is examined to establish a greater understanding of this physical model. For example, the four tables depicted in Figure 11 provide the data to compute a FCI for each infrastructure asset. The infrastructure inventory is retrieved from the real property records to determine the asset's location and confirms the Air Force owns the asset. The current replacement value (CRV) is also retrieved from the real property records to determine the current worth of the asset. Last, the deferred maintenance and repair is retrieved from an asset's maintenance backlog to determine the amount of maintenance and repair required to restore an infrastructure asset to an acceptable condition state. These respective sources of infrastructure inventory, CRV (denominator), and deferred maintenance and repair (numerator) provide the information for the FCI. The performance modeling tool computes the FCI by dividing the CRV by the deferred maintenance and repair. The performance modeling tool then assigns a calculated FCI that corresponds with a unique identifier in the infrastructure inventory, such as a building number for each facility or location for infrastructure assets. A similar process is conducted for the remaining metrics in the improved priority equation (asset level mission dependency index, energy usage, water usage, and space utilization) to determine a priority score and ultimately objectively prioritize maintenance and repair projects for the Air Force across numerous infrastructure types at different locations.

The physical asset management model and data schema once again establish a comprehensive framework and a decision-making tool that provides guidance for the asset management process. They conclude the four phases of the data modeling process and extend to agencies with a large, varying infrastructure inventory and limited

resources. Ultimately, the model and data schema enable decision-makers to efficiently operate and maintain infrastructure in order to optimize its performance.

5.1.4.3 Physical Model Validation.

Validation of the physical model closely resembled the validation of the logical model and also used a representative sample of Air Force infrastructure to develop an example implementation of a physical model for the Air Force's infrastructure operations. The validation of the physical model involved another round of informal, conversational meetings that were conducted in the same manner as the meetings for the logical model validation (stage 1 to 3). The meeting minutes (stage 4) from the discussions that transpired with asset management experts are located in Appendix C. The analysis (stage 5) again highlights one key finding from the conceptual model phase, that the data and MMS required for strategic level asset management do not align with the data and MMS required for tactical level asset management. This incompatibility in data management hinders communication between vertical as well as horizontal levels and stifles a streamlined top-down, bottom-up approach (Vanier, 2001b:40-41). As a result, each vertical level focuses on the issues and solutions that pertain solely to that level, instead of resolutions that are in the best interest of all levels. Chapter 7 expands upon this key finding as well as the conclusions drawn from it. The asset management experts verified (stage 6) the results of the Air Force physical asset management model through peer validation. This thesis document reports (stage 7) these seven stages and their results.

The validation of the general physical model and data schema confirms their utility and usability for agencies with a large, varying infrastructure set and budget

constraints. It also affirms that organizations are able to tailor a physical model and data schema to their operations and infrastructure characteristics, which establishes generalizability of the model and data schema. The strategic asset management model thus eliminates the data management incompatibility between the data and MMS required for strategic level asset management and the data and MMS required for tactical level asset management. It streamlines communication, aligns data requirements between vertical as well as horizontal levels, and formulates resolutions that are in the best interest of all levels. It also fulfills the requirement for a decision-making framework that guides the analytical process of asset management and addresses infrastructure challenges for agencies with a large, varying infrastructure inventory and limited resources.

6.0 Results – Part II

This chapter presents the results of the improved Air Force performance modeling tool. The equation, derived from the improper linear modeling process, also strives to accomplish the objectives set forth for this research project; the results once again provide conclusions and key findings that are vital to the research endeavor and contribute to the asset management body of knowledge, specifically for the Air Force. First, the improved performance modeling tool (priority equation for maintenance and repair projects) is introduced and the analysis of this equation is discussed as it pertains to the Air Force. Next, the verification of the improved tool is discussed to demonstrate that project prioritization aligns with the Air Force strategic vision and established goals and to confirm the usability of this tool to objectively prioritize maintenance and repair projects for numerous infrastructure types at various locations.

6.1 Improper Linear Modeling Process

The results from each of the four steps (initial examination of independent variables, selection of independent variables, model development, and model verification) of the improper linear modeling process are presented.

6.1.1 Initial Examination of Independent Variables for an Improved Air Force Performance Modeling Tool.

This step entailed an initial examination of infrastructure metrics as well as their data requirements and calculations to determine possible independent variables for the improved performance modeling tool. As previously stated in Section 4.1.1, the literature review established an understanding of these possible independent variables, their

relationships, and effects resulting from connections among variables. It also established a link between the possible independent variables and business practices of asset management. Additionally, the literature review provided a working knowledge along with advantages and disadvantages of the infrastructure metrics of the current and recently adopted Air Force performance modeling tools. These Air Force modeling tools provided a thorough understanding of the present prioritization process for maintenance and repair projects across various types of infrastructure assets. Thus, this initial examination established a knowledge basis for the possible independent variables to be fully comprehended and provided a foundation for the selection of independent variables.

6.1.2 Selection of Independent Variables for an Improved Air Force Performance Modeling Tool.

The selection of independent variables involved defining the objective of the improved performance modeling tool, which encompassed developing an equation of measureable infrastructure metrics that aligns with the strategic vision, goals, and policies of the Air Force to objectively prioritize maintenance and repair projects for numerous infrastructure types. This objective focused the selection criteria on specific, measureable targets that embodied the Air Force's established goals, specifically the "20/20 by 2020" goal (space utilization), Energy Independence and Security Act (EISA) of 2007 goal (energy), and Executive Order 13514 goal (water).

By executing the seven stages (thematizing, describing, meeting, transcribing, analyzing, verifying, and reporting) that were illustrated in Figure 7, asset management experts selected the independent variables for the improved Air Force priority equation. The thematization (stage 1), design (stage 2), and meeting (stage 3) stages of the

informal, conversational meetings remained consistent throughout the meetings conducted for the strategic asset management model (Sections 5.1.2, 5.1.3.2, and 5.1.4.3). Meeting minutes (stage 4), which are located in Appendix D, documented the key points, themes, and topics discussed with experts from Air Force asset management offices and research entities that arose during these meetings; the analysis (stage 5) and verification (stage 6) of the improved performance modeling tool are discussed in the following paragraphs. Last, this thesis document communicates and reports (stage 7) these seven stages and their results.

The framework of the improved performance modeling tool developed through the improper linear modeling process, illustrated in Figure 8, is presented in Equation (6).

$$\textit{Priority} = w_1(\textit{Asset Level MDI}) + w_2(\textit{FCI x 100}) + w_3(\textit{Energy}) + w_4(\textit{Water}) + w_5(\textit{Space Utilization}) \tag{6}$$

The improved performance modeling tool presented in Equation (6) intentionally omits a subjective metric that incorporates the preferences and influence of wing decision-makers. This equation establishes an objective foundation to aggregate and prioritize maintenance and repair projects across an entire organization. The intent is to aggregate and prioritize maintenance and repair projects at the operational (major command) level or strategic (headquarters) level. A continually shrinking budget increases the importance of aggregating maintenance and repair projects at levels higher than the tactical level to determine which assets most require resource allocation. Aggregation of maintenance and repair projects at higher levels provides organizational decision-makers with a holistic view of various installations to allocate limited resources amongst

numerous locations. Strategic and operational leaders should allow tactical leaders at the local level to advocate for particular projects; depending upon the circumstances, though situations may arise that result in a slight fluctuation in the priority order of maintenance and repair projects. The strategic and operational leaders should analyze these situations on a case by case basis to determine any adjustments in the priority order. This process objectively prioritizes maintenance and repair projects as well as considers the holistic view of the resulting priority order, while providing flexibility to leaders at the local levels.

The asset level mission dependency index (MDI) conveys infrastructure importance as well as criticality and assigns a score that represents the impact that incapacity or destruction of an asset would have on operations. The facility condition index (FCI) is defined in the literature review (Section 2.5.5) and is an established performance metric utilized by industry as well as the Air Force. Additional research endeavors are devoted to determining the energy and space utilization metrics of Equation (6). One thesis from the Air Force Institute of Technology is dedicated to identifying the energy metric and another thesis is dedicated to identifying the space utilization metric. A future research effort that identifies the water metric is recommended. Another future research effort is also suggested that validates the improved performance modeling tool by incorporating the energy and space utilization metrics from these research endeavors as well as the water metric from future research into Equation (6) to implement the improved performance modeling tool.

Each independent variable in Equation (6) was selected intentionally and for a purposeful reason to ensure mission accomplishment, as well as to align the tool with the

established Air Force strategic vision and goals. For instance, the asset level MDI was selected to maintain a link between infrastructure and mission accomplishment at the asset level across the Air Force. This infrastructure metric incorporates differences in mission and idiosyncrasies in infrastructure operations from one installation to another; it also accounts for interdependencies among infrastructure assets, intradependencies within infrastructure assets, and the scope of operations affected by the inoperability of a particular asset. This infrastructure metric derives interdependency and intradependency scores from the responses to structured interview questions with numerous decision-makers to formulate a statistically sound MDI score from their judgments and the number of missions impacted (Antelman, 2008:1). The asset level MDI metric allows decision-makers to utilize their expertise to account for infrastructure challenges that are distinct to each installation in order to compare the importance and criticality among specific assets. Also, this metric captures the importance and criticality of an infrastructure asset in a statistically sound manner that has already been tested, proven, and implemented with the United States Navy, United States Coast Guard, National Park Service, and the National Aeronautical and Space Administration (Antelman, 2008:1). Thus, the MDI infrastructure metric accommodates the interdependencies and intradependencies intrinsic to coupled infrastructure and accounts for decision-makers' risk tolerances to communicate the link between an asset and the mission, which is one critical component to objectively prioritizing maintenance and repair projects and allocating limited resources across numerous types of infrastructure assets.

The FCI was selected to incorporate the condition state (deferred maintenance and repair and current replacement value) of infrastructure assets into the priority score.

Specifically, this infrastructure metric provides a representation of the deferred maintenance and repair work in comparison to the current replacement value of infrastructure. Although the numerator of the FCI metric can be influenced by decision-makers (Section 2.6.5.1), it provides a benchmark with simple calculations and minimal data collection to compare the relative condition of infrastructure assets. Additionally, the use of the calculated FCI, rather than the Q-rating categories, provides a more accurate reflection of the condition state of infrastructure assets. The alternative to the FCI metric is to physically assess each component (e.g., roof and electric) of each infrastructure asset. Although this alternative provides precise condition state data, intermittent data maintenance, collection, and updates are required to ensure that the data accurately reflect the condition of each infrastructure component. The tremendous cost and manpower required to accurately capture and maintain component condition state data for the Air Force's 139,556 infrastructure assets would significantly reduce the available budget for maintenance and repair projects. A balance must be achieved between the cost and labor required to maintain the condition state data and the accuracy of the data itself. The FCI provides this balance because of its ability to achieve a fairly accurate representation of a relative condition state in comparison to other infrastructure assets using simple calculations and minimal data collection. It also aligns with the Air Force strategic vision and allows infrastructure assets to remain within industry standards.

Additionally, energy, water, and space utilization were selected as independent variables to align the improved performance modeling tool with the established, measureable goals and policies of the Air Force. The energy infrastructure metric

incorporates the EISA (2007) goal, the water infrastructure metric incorporates the Executive Order 13514 goal, and the space utilization infrastructure metric incorporates the "20/20 by 2020" goal into the improved priority equation. There is an infrastructure metric for each of these goals to balance these goals and ensure that each goal is achieved. These infrastructure metrics should adjust as the established goals of the Air Force and their specific targets change or as additional infrastructure goals are added to allow the improved performance modeling tool to reflect the current goals of the Air Force.

6.1.3 Improved Air Force Performance Modeling Tool Development.

The selection of independent variables created the framework for the improved performance modeling tool and the development of the assigned weights to these independent variables as well as ensured that this modeling tool satisfied the necessary criteria. The 2008, 2009, and 2010 Air Force Real Property databases were examined to determine the appropriate weights for the independent variables in Equation (6). Assigning the metric categories, asset level MDI, FCI, and established goals (energy and space utilization), approximately a third of the weight ensures that each category is equally taken into consideration when formulating the priority order. The improved performance modeling tool with each independent variable's assigned weight is presented in Equation (7).

$$\begin{aligned} Priority = 0.35(Asset\ Level\ MDI) + 0.35(FCI\ x\ 100) + 0.10(Energy) + \\ 0.10(Water) + 0.10(Space\ Utilization) \end{aligned} \tag{7}$$

The asset level MDI independent variable was assigned 35 percent of the overall priority score to emphasize the link between infrastructure assets and mission accomplishment. Additionally, the FCI independent variable was assigned 35 percent of the overall priority score. The emphasis on the condition of infrastructure allows assets to remain within industry standards. Last, the energy independent variable was assigned 10 percent, the water independent variable was assigned 10 percent, and the space utilization independent variable was also assigned 10 percent. The two other thesis efforts mentioned in Section 6.1.2 determine the allotment of points on a zero to 100 scale for the energy and space utilization independent variables. A future research effort is recommended that focuses on the water infrastructure metric in order to identify its variables and allotment of points. However, these three metrics default to 50 points if a project does not affect energy usage, water usage, and space utilization. If a project decreases energy usage, water usage, and/or utilizes space in a more efficient manner, then the project receives more than 50 points for the applicable metric(s) that the project positively affects. If a project increases energy usage, water usage, and/or utilizes space in a less efficient manner, then the project receives less than 50 points for the applicable metric(s) that the project negatively affects. This incorporation of energy usage, water usage, and space utilization metrics considers the established Air Force goals and prioritizes projects across numerous infrastructure types to ensure the achievement of these goals.

The improved performance modeling tool fulfills the two mandatory criteria for improper linear models. First, the assigned weights sum to 100. Second, the boundary conditions are maintained with zero as the minimum priority score and 100 as the

maximum priority score. Ultimately, the improved performance modeling tool allows decision-makers to prioritize maintenance and repair projects in order to objectively compare various types of infrastructure at different locations and generate master priority lists for Air Force infrastructure assets. The tool also prioritizes maintenance and repair projects according to the Air Force strategic vision and established goals and effectively utilizes the limited operations and maintenance budget.

6.1.4 Improved Air Force Performance Modeling Tool Verification.

The verification of the improved Air Force performance modeling tool identified the previously discussed advantages and disadvantages of the infrastructure metrics of the current, recently adopted, and improved performance modeling tools (Sections 2.6.5.1, 2.6.5.2, and 6.1.2). It also revealed the delicate balance that a performance modeling tool must achieve between accuracy of data to generate an objective priority score and the cost as well as labor required to generate that score. The current performance modeling tool lacks accuracy of data by utilizing infrastructure metrics that require minimal data maintenance and cost to generate a priority score. The recently adopted performance modeling tool, on the other hand, obtains accuracy of data by requiring a tremendous amount of manpower and a large budget to generate a priority score. The improved performance modeling tool achieves balance between accuracy of data and the cost as well as labor required, one goal of asset management, by selecting infrastructure metrics that consider this balance, specifically target particular asset management components, and are compatible with Next Generation Information Technology initiatives.

Additionally, the strategic level asset management model developed for numerous infrastructure types (Figure 9) evaluated the current, recently adopted, and improved

performance modeling tools. The current performance modeling tool accounts for the asset management components of infrastructure inventory, condition state, as well as importance and criticality by including the infrastructure metrics of FCI and MDI; however, the current performance modeling tool does not include infrastructure metrics to account for the goals of the Air Force. Thus, the priority order generated by the current tool does not align with the established Air Force goals, which creates a disconnect from the strategic level framework and the relationships among asset management components depicted in the strategic model. The recently adopted performance modeling tool also accounts for the asset management components of infrastructure inventory, condition state, as well as importance and criticality by including the infrastructure metrics of FCI, standardized MDI, and local mission impact; however, the recently adopted performance modeling tool combines the energy and space utilization goals into one infrastructure metric and does not include an infrastructure metric to account for the water goal of the Air Force. Once again, the priority order generated by the recently adopted performance modeling tool does not align with all of the established Air Force goals, which also creates a disconnect from the strategic level framework and the relationships among asset management components depicted in the strategic model.

Additionally, the improved performance modeling tool accounts for the asset management components of infrastructure inventory, condition state (FCI), importance and criticality (MDI), and goals (energy, water, and space utilization), aligns these components with the Air Force strategic vision, and addresses infrastructure challenges. The improved model, thus, stems from the decision-making framework for numerous

infrastructure types created by the strategic level asset management model. Table 2 summarizes the aspects discussed during verification (low cost data collection and maintenance, data accuracy, condition state, importance and criticality, as well as established Air Force goals) for the current, recently adopted, and improved Air Force performance modeling tools to illustrate the characteristics that each priority equation possesses and the differences amongst the performance modeling tools.

Table 2. Summary of Air Force Performance Modeling Tools

Characteristic	Current Performance Modeling Tool Equation (2)	Recently Adopted Performance Modeling Tool Equation (4)	Improved Performance Modeling Tool Equation (7)
Low Cost Data Collection and Maintenance	X		X
Data Accuracy		X	X
Condition State	X	X	X
Importance and Criticality	X	X	X
20/20 by 2020 Goal		X	X
Energy Independence and Security Act of 2007 Goal		X	X
Executive Order 13514 Goal			X

The improved performance modeling tool thus eliminates the disconnect between the current and recently adopted performance modeling tools and the strategic vision as well as established goals of the Air Force. It also balances between accuracy of data and the cost as well as labor required to generate a priority order for maintenance and repair projects. Ultimately, the improved performance modeling tool fulfills the requirement for an improved tool that better prioritizes maintenance and repair projects across numerous infrastructure types at different locations and manages infrastructure according to the business principles of asset management.

7.0 Conclusion

In 2007, the Air Force introduced asset management, a formalized approach for maintaining infrastructure to address infrastructure challenges (shrinking budget, deterioration of infrastructure, significant project demand, financial factors as opposed to technical factors, short-term planning as opposed to long-term planning, network as opposed to individual projects, and allocating resources across asset types) and to optimize the performance of infrastructure assets. The incorporation of asset management business practices sparked two requirements. The first requirement emerged because of an absence of a comprehensive model for numerous infrastructure types to efficiently manage infrastructure assets. The second requirement emerged from deficient tools to objectively prioritize maintenance and repair projects across asset types. Thus, a requirement existed for a strategic level asset management model that creates a decision-making framework and guides the analytical process of asset management for agencies with a large, varying infrastructure inventory and limited resources; another requirement existed for an improved performance modeling tool that consists of infrastructure metrics that align with the strategic vision, goals, and policies of the Air Force to objectively prioritize maintenance and repair projects across various types of infrastructure assets at different locations.

This research effort identifies and fulfills these two requirements utilizing the data modeling process and improper linear modeling process. As a result, a strategic level asset management model that applies to agencies with a large, varying infrastructure set was developed and refined for the Air Force. An improved Air Force performance

modeling tool that directly ties infrastructure metrics to the Air Force's strategic vision, established goals, and policies was also developed. Ultimately, the outcomes from this research project enable decision-makers to utilize the strategic level model and improved tool to make decisions that link goals and policies, infrastructure inventory, condition state, importance and criticality, and budget constraints to system performance in order to effectively manage and allocate resources across numerous types of infrastructure assets.

7.1 Key Findings

The analysis conducted during this research effort highlights two key findings that pertain to the Air Force, but also apply to agencies with similar infrastructure characteristics and budget constraints. First, a discontinuity exists between the established Air Force strategic vision, goals, and policies and the current as well as recently adopted performance modeling tools. The purpose of performance modeling is to understand the maintenance and repair requirements of infrastructure assets and allow this information to shape decisions; however, the current and recently adopted Air Force performance modeling tools do not align with the organization's strategic vision, goals, and policies (McElroy, 1999:2-3).

Specifically, the "20/20 by 2020" goal aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020, the Energy Independence and Security Act (EISA) of 2007 goal aims to reduce energy usage by 30 percent by the year 2015, and Executive Order 13514 aims to reduce potable water usage by 26 percent as well as non-potable water usage by 20 percent by the year 2020; yet the current performance modeling tool does not account for

energy usage, water usage, or space utilization (Congress of the United States, 2007:Section 431; Headquarters Air Force, 2009b:1; Obama, 2009:3). Thus, a discontinuity exists between the Air Force strategic vision, established goals, and policies and the current performance modeling tool. This disconnect results in decision-makers selecting an optimal solution based upon either the strategic vision, goals, and policies or the current priority equation, but not both. These competing interests, created by this disconnect, lack synergy and cohesiveness.

Additionally, the recently adopted performance modeling tool combines the energy and space utilization goals into one infrastructure metric, which does not balance these goals to ensure that each goal is achieved. This tool also does not account for water usage. Thus, a discontinuity also exists between the Air Force strategic vision, established goals, and policies and the recently adopted performance modeling tool. This disconnect causes decision-makers to select an optimal solution based upon achieving one of the goals, but not necessarily all of the goals. Ideally, the performance modeling tool guides decisions that are related to the Air Force strategic vision, established goals, and policies to ensure that the tool's measureable metrics provide decision-makers with the necessary information to align viable approaches with these asset management components. Air Force efforts should aim to eliminate this disconnect, which is precisely what the improved performance modeling tool accomplished. The improved performance modeling tool accounts for the Air Force's infrastructure inventory, condition state, importance and criticality, policies, and goals and aligns these components with the Air Force strategic vision. This tool establishes an objective foundation to aggregate and prioritize maintenance and repair projects at the operational

level or strategic level to determine which assets most require resource allocation. The improved performance modeling tool accomplishes the ultimate goal of a performance modeling tool, to enable decision-makers to make informed, performance-based decisions that link the strategic vision, goals, policies, and budget to known aspects of system attributes (inventory, condition state, and importance and criticality) and performance (metrics and modeling tools).

Second, the data and maintenance management system (MMS) required for strategic level asset management do not align with the data and MMS required for tactical level asset management. The strategic level forecasts, requests, and justifies a long-term budget for demolition, renovation, capitalization, and maintenance and repair projects with a 10 to 12 year outlook; however, the tactical level allocates the operations and maintenance budget and advocates for short-term requirements with a one to two year outlook. The tactical level (Air Force installations) funnels data, usually in a MMS, up to the strategic level based on its own outlook. Likewise, the strategic level (Headquarters Air Force) funnels data, usually in a MMS, down to the tactical level based on its own outlook. The top-down data transfer does not consider the tactical level outlook and the bottom-up data transfer does not consider the strategic level outlook. This disparity stems from differences in operations between the two levels. Long-term planning is not a concern of the tactical level because its focus is on short-term execution, but a lack of information regarding long-term requirements results in a lack of requests for and justification of future budgets. As a result, an adequate amount of operations and maintenance funds will not be available for projects in 10 years, when what was the long-term is now the short-term. Short-term execution is also not a concern of the strategic

level, because its focus is on long-term planning and the funds for short-term execution have already been allocated to installations across various asset types.

Another issue involved is the misaligned data and MMS between the strategic and tactical levels. The Air Force Civil Engineer community collects data for, utilizes, and maintains over 10 MMS. At times, the MMS utilized by the strategic level is not the same MMS utilized by the tactical level. In these instances, the lack of compatibility between data formats hinders the top-down, bottom-up flow of data. Air Force efforts should align the data and MMS required for strategic level asset management with the data and MMS required for tactical level asset management, which is precisely what the strategic level asset management model achieves. The strategic model streamlines communication, aligns data requirements between vertical as well as horizontal levels, and formulates resolutions that are in the best interest of all levels. Aligning the required data and MMS enables transparency of data and streamlines data collection and maintenance for efficient and effective database management. The strategic level asset management model for numerous infrastructure types achieves the ultimate goal of data management, to align the MMS and required data for asset management in order for decision-makers to conceive of approaches and alternatives that are in the best interest of all vertical (tactical, operational, and strategic) levels of the Air Force.

The discontinuity that exists between the performance modeling tools (current and recently adopted) and the Air Force's strategic vision, goals, and policies as well as the differences in MMS and data required between the strategic and tactical levels causes misaligned data management at both horizontal and vertical levels. This misalignment

resulting from the disparities in data and asset management components is illustrated in Figure 12.

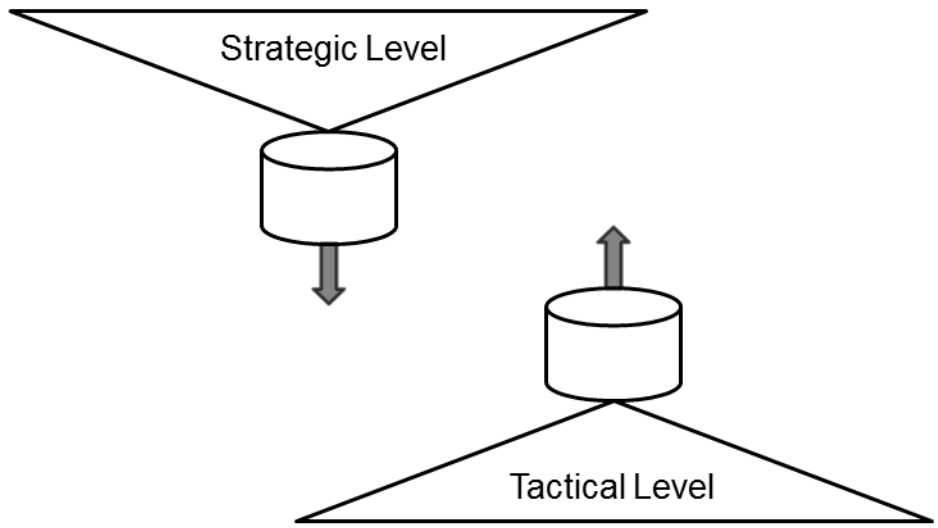

Figure 12. Data Disparity between Strategic and Tactical Levels

This research project eliminates the discontinuity between the Air Force current and recently adopted performance modeling tools and the strategic vision, established goals, and policies by developing an improved performance modeling tool. Additionally, this research effort eliminated the differences in required data and MMS between the strategic and tactical levels by developing an asset management framework. The elimination of these disparities aligned data and asset management components both at horizontal and vertical levels for the Air Force, which allows for a single enterprise level database. The development of an Air Force enterprise level database embodies several pillars of the Next Generation Information Technology Program Management Plan to include the elimination of redundant data entry, the simplification of data calls, as well as streamlined data collection, maintenance, and visibility of data at all vertical levels. The

creation of a single enterprise level database for the Air Force also furthers the implementation of asset management business practices.

Figure 13 presents the streamlined top-down, bottom-up approach created by the products of this research project in order to effectively manage and allocate resources across numerous types of infrastructure assets.

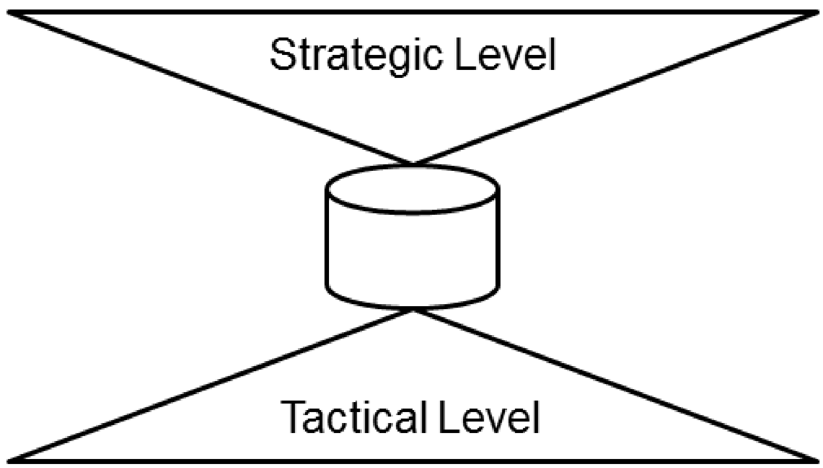

Figure 13. Data Alignment between Strategic and Tactical Levels

This figure illustrates a single enterprise level database (e.g., oracle and structured query language) with common data that align the strategic and tactical levels both vertically and horizontally. Ideally, this database serves various software systems (e.g., Geographic Information System) that the Air Force utilizes and interprets the format to create useful products. This approach of Information Technology integration allows the tactical level to provide the strategic level with data that are applicable to its focus area and vice versa, instead of the current situation where the tactical and strategic levels provide the other with information that applies to their own outlook. Thus, the focus areas and outlooks of the strategic level and tactical level vary due to the differences in operations of these

functional levels; however, efficient operations and maintenance of infrastructure requires alignment of data in order to optimize the performance infrastructure assets.

The International Infrastructure Maintenance Manual reinforces the concepts discussed of aligning required data and MMS. Figure 14 depicts the requirement to align the strategic and tactical levels of an organization with common data. It also highlights the streamlined top-down, bottom-up approach to infrastructure asset management.

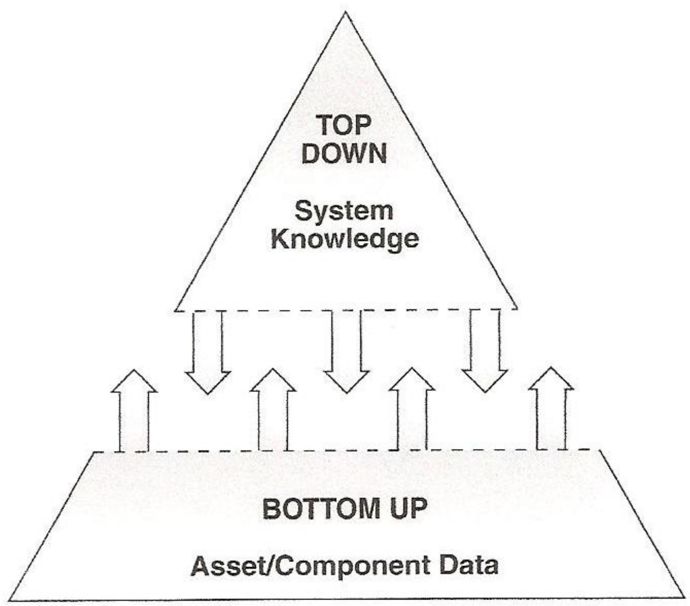

Figure 14. Top-down, Bottom-up Data Alignment Approach to Asset Management (Maunsell Project Management Team, 2006:1.9)

Figure 15 illustrates the diverse outlooks amongst the different operating levels. These varying outlooks operate utilizing common data that vertically and horizontally align the operating levels. Both figures highlight the importance of aligning required data and MMS in order for decision-makers to conceive of approaches and alternatives that are in the best interest of all vertical (tactical, operational, and strategic) levels of the Air Force.

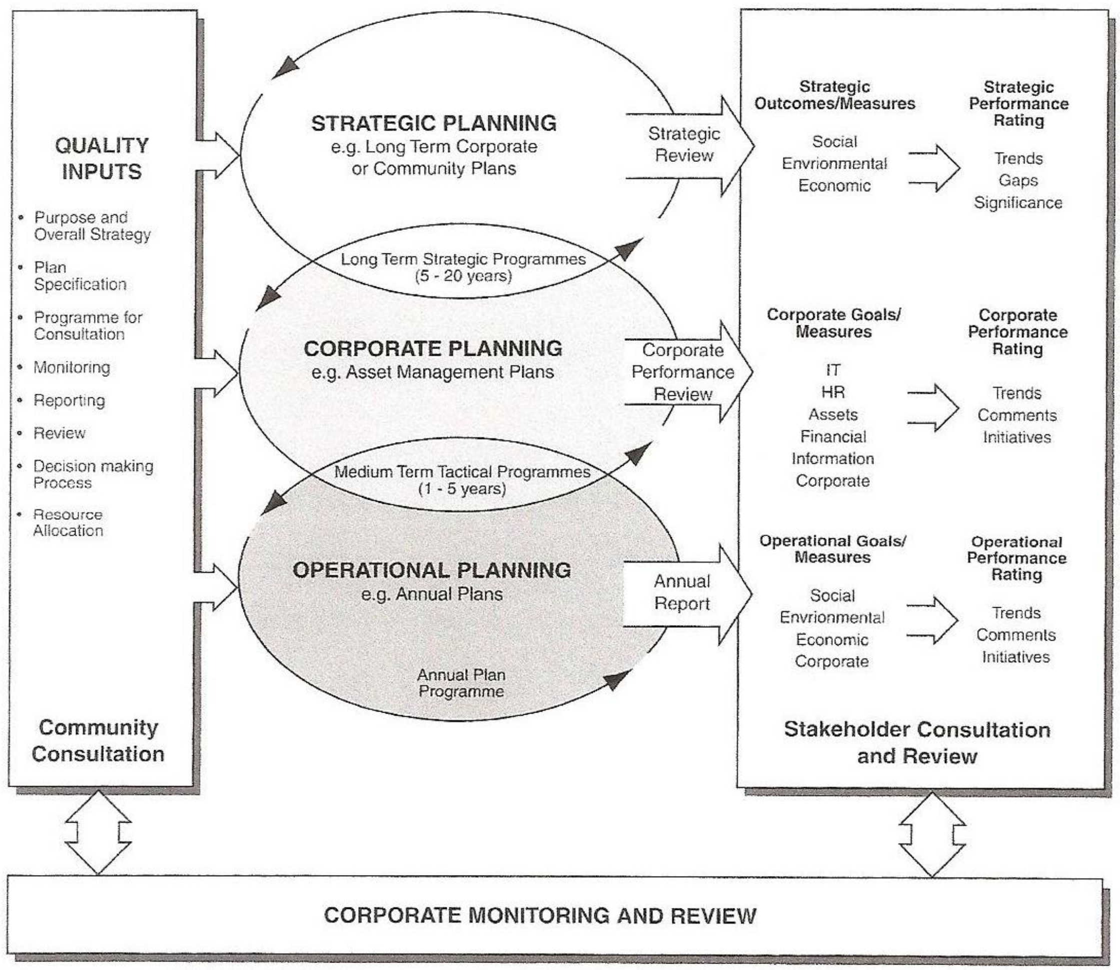

Figure 15. Operating Levels with Diverse Outlooks (Maunsell Project Management Team, 2006:2.5)

In addition to the streamlined flow of data, the utility of this research lies in its two products that contribute toward the asset management body of knowledge and optimize the performance of numerous infrastructure types at various locations. First, the strategic level model establishes a comprehensive framework to provide guidance for asset management business principles, specifically for agencies with a large, varying infrastructure inventory and limited resources. Second, the improved Air Force performance modeling tool allows decision-makers to prioritize maintenance and repair

projects in order to objectively compare various types of infrastructure at different locations and generate master priority lists for Air Force infrastructure assets.

7.2 Limitations of Current Research

The main limitations involved in implementing the strategic level asset management model and improved performance modeling tool are the availability of accurate data, the judgments of experts, and the allocation of funds. The strategic asset management model relies on the availability of accurate data to illustrate the relationships among the components of asset management and integrate these components into a useful decision support system. The improved performance modeling tool also relies on the availability of accurate data to objectively prioritize maintenance and repair projects for numerous infrastructure types for the Air Force. Without accurate data, these models and tool are not able to optimize the performance of infrastructure assets or effectively utilize the limited operations and maintenance budget. Additionally, the development of the strategic level asset management model and improved performance modeling tool utilized the judgments of experts. These experts maintain a vast knowledge and expertise regarding asset management; however, their perspectives and judgments are subjective and can vary from expert to expert. Hence, numerous asset management experts participated in this research effort in order to create a consensus amongst the experts and establish peer validation of the responses and concepts. Last, the implementation of the strategic level asset management model and improved performance modeling tool hinge on the allocation of funds based on an objective perspective of what infrastructure the Air Force needs to fix first. Funds are currently provided to decision-makers to allocate and

execute at their discretion. Ideally, these decision-makers implement the strategic model and improved tool as they were intended to be utilized (to effectively manage and allocate resources as well as objectively prioritize maintenance and repair projects across numerous types of infrastructure assets) without adjusting or influencing the results of the model or priority score. The strategic level asset management model and improved performance modeling tool strive to diminish subjective factors to optimize the performance of infrastructure assets as well as objectively compare various types of infrastructure at different locations to generate master priority lists for Air Force infrastructure assets. Limitations are present in every research effort; thus, agencies implementing the strategic level model and improved performance modeling tool should understand these three limitations (availability of accurate data, judgments of experts, and allocation of funds).

7.3 Future Research

Suggested future research discusses facets of the strategic asset management model and improved performance modeling tool not encompassed in the scope of this thesis. One proposed future research effort involves determining the water metric for the improved performance modeling tool. The focus of this research involves:

- Identification of the infrastructure metric(s) for water to include in the improved performance modeling tool
- Establishment of a zero to 100 point allocation for the water metric
- Validation of the water metric for a representative sample of Air Force infrastructure
- Implementation of the water metric that aligns with established goals and is compatible with Next Generation Information Technology (IT) initiatives

Additional future research involves the validation of the improved performance modeling tool. The focus of this research involves:

- Infrastructure metrics purposefully included and excluded in the improved performance modeling tool
- Comparison among industry performance modeling tools, the Department of Defense performance modeling tools, and the improved Air Force performance modeling tool
- Comparison among the priority orders produced by the current, recently adopted, and improved Air Force performance modeling tools
- Implementation of the improved performance modeling tool utilizing the energy, water, and space utilization infrastructure metrics from other thesis efforts and future research

A third proposed future effort involves the integration of a fully developed physical asset management model with Air Force MMS. Ideally, this research would align with Next Generation IT initiatives and further streamline the top-down, bottom-up flow of data. The follow-on physical model research should occur after the water metric and improved performance modeling tool research in order to tailor a fully developed physical model to the improved priority equation. The focus of this research involves:

- Comparison among Air Force MMS, including their compatibility among MMS
- Integration of the physical model with Air Force Next Generation IT
- Implementation of the physical model utilizing Air Force MMS

These proposed research efforts would further the asset management knowledge associated with the strategic level model and improved tool that this thesis developed.

7.4 Summary

This research identifies two requirements that were fulfilled by developing a strategic level asset management model for numerous infrastructure types, using the data modeling process, and an improved Air Force performance modeling tool, using the improper data modeling process. One purpose of this research was to create a comprehensive model that provides a framework and guides the analytical process of asset management for agencies with a large, varying infrastructure inventory and limited resources. Another purpose of this research was to create an improved tool that allows decision-makers to prioritize maintenance and repair projects in order to objectively compare various types of infrastructure at different locations and generate master priority lists for Air Force infrastructure assets. The research effort discusses two key findings, data disparities both at horizontal and vertical levels as well as performance modeling tools that do not account for Air Force goals. The products of this research (strategic asset management model for numerous infrastructure types and improved performance modeling tool) align data at all levels to streamline the top-down, bottom-up flow of information and reflect the strategic vision, goals, and policies of the Air Force.

Appendix A. Asset Management Concepts

Meeting Focus: Asset Management Concepts

Date: 4 March 2011

Organizations Represented:

- Headquarters Air Force Asset Management and Operations Office
- Wright-Patterson Air Force Base
- Air Force Institute of Technology
- Air Force Civil Engineer School

Topics Discussed:

- Asset management components (strategic vision, infrastructure inventory, condition state, importance and criticality, goals, budget, decision-making, execution, and feedback)
- Definitions and concepts surrounding the components of asset management
- Decision-support tools to appropriately identify requirements and allocate funds
- Headquarters Air Force projects maintenance and repair projects as well as funds many years out
- Installations project maintenance and repair projects as well as funds a few years out
- Need for analysis to bring short-term planning and long-term planning together; elimination of the misaligned data and incompatibility between maintenance management systems
- Problem domain for research effort, specifically for agencies with a large, varying infrastructure inventory and limited resources
- Discontinuity between Air Force strategic vision and performance modeling tools

Appendix B. Logical Air Force Asset Management Model Validation

Meeting Focus: Logical Air Force Asset Management Model Validation

Dates: 4 May 2011 and 12 August 2011

Organizations Represented:

- Headquarters Air Force Asset Management and Operations Office
- Air Force Material Command
- Air Force Institute of Technology
- Air Force Civil Engineer School

Topics Discussed:

- Asset management components (strategic vision, infrastructure inventory, condition state, importance and criticality, goals, budget, decision-making, execution, and feedback)
- Logical asset management model and its implementation
- Air Force asset management components (strategic vision, infrastructure inventory, condition state, importance and criticality, goals, budget, decision-making, execution, and feedback for the Air Force)
- Tailoring the logical asset management model to the Air Force
- Logical Air Force asset management model and its implementation
- Discontinuity between Air Force strategic vision, established goals, and performance modeling tools
- Importance of transparent as well as streamlined data collection and maintenance
- Conformation of the logical asset management model's usability and generalizability for any agency with a large, varying infrastructure inventory and limited resources

Appendix C. Data Schema of the Air Force Physical Asset Management Model Validation

Meeting Focus: Physical Asset Management Model Validation

Date: 21 October 2011

Organizations Represented:

- Headquarters Air Force Asset Management and Operations Office
- Air Force Material Command
- Air Force Institute of Technology
- Air Force Civil Engineer School

Topics Discussed:

- Physical asset management model requirements and its implementation
- Next Generation Information Technology and maintenance management system requirements to support a physical Air Force Asset Management model
- Physical Air Force asset management model requirements and its implementation
- Need for analysis to bring short-term planning and long-term planning together; elimination of the misaligned data and incompatibility between maintenance management systems
- Importance of transparent as well as streamlined data collection and maintenance
- Conformation of the physical asset management model example's usability for any agency with a large, varying infrastructure inventory and limited resources

Appendix D. Selection and Weights of Independent Variables for an Improved Air Force Performance Modeling Tool

Meeting Focus: Selection of Independent Variables

Dates: 12 August 2011 and 26 August 2011

Organizations Represented:

- Air Force Material Command
- Wright-Patterson Air Force Base
- Air Force Institute of Technology
- Air Force Civil Engineer School

Topics Discussed:

- Purpose and goals of the improved Air Force performance modeling tool
- Infrastructure metrics from industry and infrastructure metrics/independent variables of the current as well as recently adopted performance modeling tools
- Advantages and disadvantages of these infrastructure metrics and independent variables
- Discontinuity between Air Force strategic vision, established goals, and current as well as recently adopted performance modeling tools
- Selection criteria for the independent variables of the improved tool
- Balance must be achieved between the cost and labor required to maintain the condition state data and accuracy of the data itself
- Infrastructure metrics/independent variables and their weights to include in the improved performance modeling tool
- Advantages and disadvantages of the selected infrastructure metrics/independent variables in the improved performance modeling tool

Appendix E. Improved Air Force Performance Modeling Tool Verification

Meeting Focus: Asset Management Concepts

Date: 21 October 2011

Organizations Represented:

- Headquarters Air Force Asset Management and Operations Office
- Air Force Material Command
- Air Force Institute of Technology
- Air Force Civil Engineer School

Topics Discussed:

- Weights selected for each infrastructure metric/independent variable in the improved Air Force performance modeling tool
- Compatibility with Next Generation Information Technology initiatives
- Balance must be achieved between the cost and labor required to maintain the condition state data and accuracy of the data itself
- Advantages and disadvantages of the priority order generated by the current, recently adopted, and improved performance modeling tools
- Evaluation of each priority equation (current, recently adopted, and improved) using the strategic level asset management model framework
- Confirmation of the improved Air Force performance modeling tool's utility and ability to generate an outcome given a set of data
- Usefulness of the improved performance modeling tool to objectively compare various types of infrastructure at different locations and generate master priority lists for Air Force infrastructure assets

Appendix F. Strategic Infrastructure Asset Management Modeling Conference Paper for Western Decision Sciences Institute Forty First Annual Meeting

ABSTRACT

Effective asset management requires an overarching model that establishes a framework for decision-makers. A model also provides guidance for asset management business principles and illustrates the relationships among the components of asset management. This paper presents a strategic level asset management model that is applicable to agencies with a large infrastructure inventory and limited resources. This model highlights how the components tie together and influence each other to provide a holistic perspective of asset management. Decision-makers can use this model to make decisions that tie policies, infrastructure inventory, condition state, and budget constraints to system performance. Asset management of Air Force infrastructure provides an example of applicability for this model that aligns with the Next Generation Information Technology initiatives. The Air Force asset management example is weaved throughout the research project to demonstrate the utility of the model. As a result, insight is gained on ways to maximize efficiency and optimize the performance of infrastructure.

INTRODUCTION

Budget constraints and scarce resources have sparked agencies to maximize efficiency when operating and maintaining aging infrastructure. For example, the United States Air Force currently manages 139,556 infrastructure assets (facilities, runways, utility lines, and roadways) valued at 263.43 billion dollars [7]. In order to optimize the performance of these infrastructure assets, the Air Force (AF) Civil Engineer (CE) career field

introduced a formalized approach for maintaining infrastructure and labeled this approach asset management [8]. Asset management, the foundation of the CE transformation which began in 2007, involves business practices that emphasize management techniques to focus and maximize limited resources [4]. The purpose of asset management is to meet a required level of service in the most cost effective manner while adhering to established goals and policies as well as remaining within budget constraints [14].

Along with introducing asset management, AF senior leadership restructured CE organizations at all levels during the CE transformation [4]. The incorporation of asset management functions at all vertical organizational levels (unit level, major command level, and headquarters level) created an emphasis on planning and implementing asset management principles in daily decision-making. Although the asset management culture is present throughout all levels of the corporate structure of CE organizations, there is an absence of a comprehensive framework to provide guidance for asset management business principles, which results in deficient project management tools for decision-making. As such, a requirement exists for a strategic level model. This strategic level model should illustrate the relationships among the components of asset management and integrate these components into a useful, decision-making tool in order to optimize the performance of infrastructure [18].

INFRASTRUCTURE CHALLENGES

Four challenges sparked the requirement for a strategic level model: financial factors as opposed to technical factors, short-term planning as opposed to long-term planning, network as opposed to individual projects, and allocating resources across asset types [3]. The financial factors, such as cost of maintenance and repair projects, are

weighed against technical factors when implementing a solution. This constant challenge is exacerbated by a shrinking budget and by the monetary cost of necessary projects exceeding the funds available for these projects. Under these circumstances, "asset managers must allocate funds among competing, yet deserving requirements" [23, p. 4]. Short-term remedies are evaluated against long-term goals. A short-term fix may not be the most economical solution and a long-term strategy may not be the timeliest solution [4]. The difficulty in balancing short and long-term factors significantly increases with rapidly changing targets and goals. These challenges hinder the ability to assess and delineate short-term and long-term budgets and priorities, creating an increasingly difficult task.

Additionally, infrastructure is an integrated system with individual components that function independently and in conjunction with other systems [24]. The interconnectedness of infrastructure links assets into a complex system of interrelated elements [17]. This concept of infrastructure coupling correlates the state of one infrastructure asset to the state of another, which creates an interdependency between the two [7]; however, most maintenance management systems (MMS) assess only individual components or isolated projects, instead of accounting for network goals and coupling effects. These individual projects are weighed against networks in which infrastructure is constrained by the weakest link or networks where parts should be replaced simultaneously in neighboring systems.

Last, budget constraints for maintenance and repair projects require decision-makers to allocate resources across asset types while considering the value an asset has to an agency's operations and the current condition of the infrastructure. The difficulty in

allocating resources across numerous types of infrastructure assets is driven by the issue of objectively comparing the worth and importance of infrastructure assets. Rapidly changing leadership and goals along with these issues create an increasingly challenging task, to delineate among assets and determine which most require resource allocation. The contending factors of financial as opposed to technical, short-term planning as opposed to long-term planning, network as opposed to individual projects, and allocating resources across asset types provide challenges and opportunities for decision-makers. Agencies with a large, varying infrastructure set and limited resources require a strategic asset management model that properly balances these infrastructure challenges by creating a useful decision support system to guide the analytical process of asset management.

DATA MODELING PROCESS

Longley et al.'s data modeling process was used to create a logical asset management model that incorporates the components of asset management [13]. This method of data modeling is a type of systems modeling that defines and analyzes data requirements to support the business practices of an agency [2]. Specifically, "a data model is a set of constructs for representing objects and processes in digital form" [13, p. 178-179]. A data model also involves ontologies, which define the components of a system and associate them in classes, relationships, or functions [11]. Data modeling consists of four levels (listed in order of increasing abstraction): reality model, conceptual model, logical model, and physical model [13].

Data modeling is particularly applicable to projects that require management of data as a resource, integration of information systems, and modification of databases for

organizational operations [25]. Specifically for the scope of this research project, data modeling focused on asset management processes for agencies with large infrastructure sets and the data required to make decisions based upon the strategic components of these infrastructure systems. The result of this data modeling process, in the context of the Air Force, will align with the Next Generation Information Technology Program Management Plan objective to streamline the required data and its transparency. Thus, this paper presents a logical model for strategic level asset management that followed the first three phases of the data modeling process.

Logical Model

Development of the logical asset management model produced a strategic level model of an operational infrastructure system. This logical model consists of components, defined and described in the reality model and conceptual model phases, that are prevalent to the business practices of asset management. The model was submitted for publication and graphically depicts influential strategic components as well as their relationships that are vital to the asset management process [21]. It also illustrates the ontologies and associations among the asset management components and identifies the data required to promote analysis of infrastructure operations. The unpublished work presents the general logical asset management model and provides an understanding of the strategic components depicted in the model as well as the relationships among these components.

The logical asset management model creates a comprehensive framework that provides guidance for the asset management process. It serves as a useful, decision-making tool that is applicable to agencies with a large infrastructure inventory and limited resources. This model enables decision-makers to formulate viable approaches and alternatives to

infrastructure management and facilitates efficient use of the annual operations and maintenance budget in order to optimize the performance of infrastructure assets.

This paper used a representative sample of Air Force infrastructure to tailor the general logical model specifically to infrastructure operations of the Air Force [21]. Figure 1 presents the logical model validation, which modifies the general logical model to the Air Force's asset management process, depicts the components as they pertain to this specific organization, incorporates the Air Force entities prevalent to each component, and identifies the data required for analysis of its infrastructure systems. It also illustrates the importance of transparent data as well as streamlined data collection and maintenance, which Next Generation Information Technology aims to achieve for the Air Force [22]. In essence, the logical Air Force asset management model, presented in Figure 1, creates a decision-making framework for the Air Force that guides the analytical process of asset management and addresses infrastructure challenges, specifically for this organization.

The strategic asset management components illustrated in the logical model comprise the process of asset management for the Air Force.

Strategic Vision (*Air Force)* - Articulation and implementation of the strategic vision occurs both horizontally and vertically throughout the organization. Knowledge of the desired end state allows decision-makers to prudently dedicate resources to the operation, maintenance, and repair of infrastructure assets. Department of Defense (DoD) strategic level documents provide overarching guidance that the Air Force implements through its own strategic vision and operations. According to the strategic vision of the Air Force Civil Engineer, civil engineers seek to "provide sustainable installations by using transformational business practices" [16, p. 1]. This strategic vision highlights the use of

asset management principles in daily operations and currently guides data collection, budgets, policies, and goals for the Air Force.

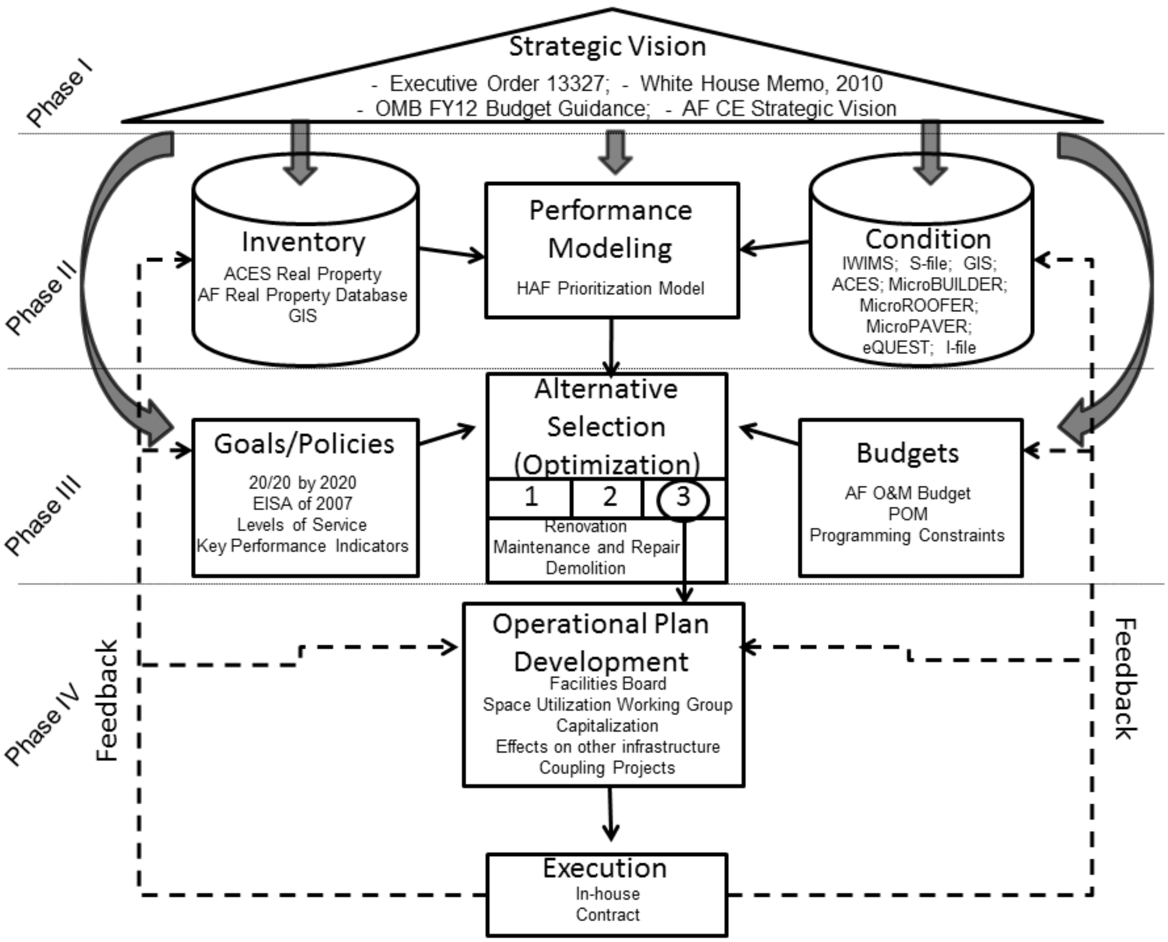

FIGURE 1. Logical Air Force Asset Management Model

Inventory (*Air Force)* - The Air Force owns an incredibly diverse set of constructed facilities ranging from dormitories to aircraft hangars to warehouses [15]. These facilities support a myriad of government functions and are located on various continents. The age of the 139,556 infrastructure assets in the Air Force's inventory spans decades, and sometimes centuries, of building design and construction technologies [7]. The Air Force collects and maintains data for its infrastructure inventory and condition state of

infrastructure in order to generate a snapshot of its assets; however considerable information technology (IT) issues exist because current data management systems do not effectively communicate with each other and data is entered multiple times into multiple data management systems [22]. As a result, individuals develop and maintain spreadsheets and databases of their own to compensate for inadequate systems.

Condition (*Air Force)* - The Air Force collects condition state data in a maintenance management system (MMS), called the Interim Work Information Management System (IWIMS), tailored specifically for military operations. The Air Force carries over approximately 9.3 billion dollars of maintenance and repair backlog each year, which amounts to 3.5 percent of its current replacement value (CRV) [10]. This quantity of deferred maintenance and repair is above the recommended industry standard of one to two percent residual from year to year [10].

Performance Modeling (Air Force) - Performance modeling for the Air Force serves as the primary tool to prioritize maintenance and repair requirements and utilizes an equation with infrastructure metrics to rank order projects. The goal in shaping our maintenance and repair decision is to choose the most economical approach (from a life-cycle standpoint) to answer the question, what should be fixed first? [19] [20] [23]. These tools, in essence, guide decisions that are related to the established strategic vision. Thus, a dependency exists between the performance model tool and the strategic vision to ensure that the measureable components of the tool provide decision-makers with the necessary information to align viable approaches with the strategic vision.

Goals and Policies (*Air Force)* - To align with the strategic vision of providing sustainable installations by using transformational business practices, the Air Force

coined "20/20 by 2020" as one of its goals. "20/20 by 2020" aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020 [4]. The Energy Independence and Security Act of 2007, which aims to reduce energy usage by 30 percent by the year 2015 and the "20/20 by 2020" goal are specfic, measureable targets that align with the Air Force strategic level vision; however, the advancement of these goals is limited by available funding.

Budget (Air Force) - Currently, the Air Force allocates 2.5 billion dollars annually to maintenance and repair projects [7]. This budget amounts to 0.95 percent of its CRV, which is significantly lower than the recommended industry standard of two to four percent [23]. With limited resources available, the budget provides boundaries (constraints) for selecting alternatives in order to manage assets from a holistic perspective and make the best decisions possible.

Alternative Selection (*Air Force)* - Alternative selection explores options associated with infrastructure assets to determine which approach is in the agency's best interest. Under the operations and maintenance budget, the Air Force examines five potential resolutions of demolish, continue to maintain and repair, construct an asset with capitalization, renovate, or status quo when determining the most advantageous solution [5].

Operational Plan Development (*Air Force)* - The purpose of operational plan development is to examine how the preferred course of action impacts an agency's infrastructure from a second and third order effect perspective. Once an optimal solution is determined, operational plan development considers how to leverage efficiency from infrastructure networks and how the proposed course of action affects other aspects of these assets [3]. Along with addressing how the optimal solution affects current

maintenance and repair projects, planning for future endeavors as well as future maintenance and repair projects occurs as a part of operational plan development. Capitalization, known as military construction (MILCON), constructs a new infrastructure asset that improves capability and corrects infrastructure issues. However, MILCON falls under a separate budget with direct congressional oversight and approval; it does not compete with operations and maintenance funds.

Execution (Air Force) – Execution implements the optimal solution to utilize limited resources in the most effective manner in order to optimize the performance of infrastructure assets. In the case of the Air Force, execution involves coordinating the labor and funding to carry out the demolition, maintenance and repair projects, and/or renovation.

Feedback (*Air Force)* - Asset management for the Air Force is an iterative process that requires a feedback loop. The strategic vision, goals, and policies are in constant flux with the continual movement of headquarters staff personnel and commanders. Additionally, the operations and maintenance budget varies from year to year [9]. Thus, Air Force decision-makers examine results and address changes during feedback, prior to beginning the iterative process of asset management again.

KEY FINDINGS

Analysis of the Air Force logical model highlights and emphasizes two key findings. A discontinuity exists between the established strategic vision, goals, and policies and the current performance modeling tool. Hence, decisions regarding maintenance and repair of infrastructure do not reflect or account for the strategic vision, goals, and policies of the Air Force. For example, the “20/20 by 2020” goal aims to reduce both the physical

square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020, and the Energy Independence and Security Act of 2007 aims to reduce energy usage by 30 percent by the year 2015; however the current equation (performance modeling tool) that prioritizes maintenance and repair projects does not account for energy usage or space utilization. The disconnect between these components results in decision-makers selecting an optimal solution based upon either the strategic vision, goals, and policies or the priority equation, but not both. These competing interests, created by this disconnect, lack synergy and cohesiveness.

Additionally, the data and MMS required for strategic level asset management do not align with the data and MMS required for tactical level asset management. Thus, the lack of compatibility and proper communication hinders the flow of data between vertical levels and stifles a streamlined top-down, bottom-up approach that enables decision-makers to formulate viable courses of action [4]. As a result, each vertical level focuses on the issues and solutions that pertain solely to that level, instead of resolutions that are in the best interest of all levels; ideally, the approaches and alternatives conceived by the decision-makers are in the best interest of all vertical levels (tactical, operational, and strategic) of the Air Force.

FUTURE RESEARCH

Suggested future research for this project involves the development of a physical asset management model and an improved performance modeling tool. The physical asset management model will visualize, construct, and specify the data requirements for each of the strategic components of the asset management process. It will also portray the actual, computer-oriented implementation and demonstrate how objects are digitally

implemented [20]. The physical asset management model and data schema will complete the data modeling process. With a fully developed model, the Air Force will have a comprehensive framework and decision-making tool that provides guidance for the asset management process.

Additionally, the discussion of Air Force asset management components highlights the requirement for an improved performance modeling tool that aligns with the strategic vision, goals, and policies of the Air Force to objectively prioritize maintenance and repair projects. The components of the Headquarters Air Force prioritization model, the current performance modeling tool that rank orders maintenance and repair projects, do not measure all of the performance metrics established by Air Force asset management goals and policies. This disconnect results in competing interests and a lack of synergy between the goals and current performance modeling tool. The lack of a cohesive focus between these two components affects the operational plan development and execution of demolition, renovation, and/or maintenance and repair projects; limited resources are not effectively utilized in a manner that aligns with the strategic vision or goals. Thus, an improved performance modeling tool that incorporates the goals and policies of the Air Force is necessary to objectively prioritize maintenance and repair projects across all major commands.

CONCLUSION

The Air Force introduced asset management into the organization to maximize limited resources and to optimize the performance of infrastructure assets [4]. A requirement for a comprehensive asset management model emerged as a result of the culture shift to asset management and its business practices. This paper adapts a strategic asset management

model specifically to the Air Force, that establishes an overarching framework for the decision-making process. It also provides explanations of the strategic components of the model and illustrates relationships among these components. The relationships depicted and described represent critical links between the model's components. The decision process ties the goals, planning, and execution to the strategic vision; the strategic vision guides and shapes the entire process and each component of the model.

The purpose of the proposed model is to provide an objective structure for decision-makers to evaluate the impacts and trade-offs of current and future viable approaches and alternatives. The model provides an analytical process and cost-effective strategies through a structured framework for the iterative processes of asset management. The holistic perspective of infrastructure assets that this model affords is relevant to agencies with large infrastructure inventories and limited budgets. Thus, this proposed strategic asset management model is widely applicable to large organizations, such as the military, large corporations, and universities. It also allows these agencies to maximize their scarce resources and optimize the performance of their infrastructure assets.

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Appendix G. Infrastructure Asset Management Modeling through a Strategic Assessment of Air Force Asset Management Manuscript for Journal of Infrastructure Systems

William E. Sitzabee, Ph.D., P.E. and Marie T. Harnly

Abstract

Effective asset management requires a comprehensive framework for decision-makers. This paper develops a comprehensive asset management framework for varying types of infrastructure assets that provides guidance for effective asset management. The framework also incorporates Next Generation Information Technology initiatives into a single coherent system in order to streamline the top-down, bottom-up flow of information. The comprehensive asset management framework is applicable to agencies with a large, varying infrastructure inventory and limited resources. Additionally, this paper develops a performance modeling tool, a critical component of the framework. The performance modeling tool objectively prioritizes maintenance and repair projects according to measurable metrics as well as the strategic vision, established goals, and policies. Asset management of Air Force infrastructure provides an example of applicability for this comprehensive framework and performance modeling tool. The Air Force asset management example is weaved throughout the paper to demonstrate the utility of the comprehensive asset management framework and the performance modeling tool. The framework and performance modeling tool enable policy-makers to make decisions that tie goals, infrastructure inventory, condition state, importance and criticality, and budget constraints to system performance. As a result, asset managers

gain insight on ways to maximize efficiency and optimize the performance of infrastructure.

Key Words

Asset Management, Infrastructure Management, Information Technology, Process Modeling

Introduction

Budget constraints and scarce resources have sparked agencies to maximize efficiency when operating and maintaining aging infrastructure. For example, in 1998, the Federal Highway Administration (FHWA) reorganized and created an asset management office to address the ongoing deterioration of the highway system, significant project demand, and a stretched budget (United States Department of Transportation, 1999). This restructuring resulted from a mindset shift that occurred once the Interstate Highway System was completed in 1992. The FHWA adjusted its focus from an emphasis on new construction to an emphasis on maintenance and management of four million miles of existing interstate infrastructure (highways and roads). As a result, the FHWA reorganized and became one of the first large agencies to implement asset management. Ultimately, the FHWA adopted asset management principles to maintain, upgrade, and operate its infrastructure assets in a cost effective manner.

Similarly, in 2007, the United States Air Force Civil Engineers introduced a formalized approach for maintaining infrastructure and labeled this approach asset management in order to optimize the performance of the 139,556 infrastructure assets (facilities, runways, utility lines, and roadways), valued at 263.43 billion dollars (Culver,

2007; Department of Defense, 2010; Eulberg, 2008). Along with introducing asset management, Air Force senior leadership restructured Civil Engineer (CE) organizations and incorporated an asset management function at all vertical levels to address similar issues that faced the FHWA: shrinking budget, deterioration of infrastructure, significant infrastructure project demand, and infrastructure challenges. Specifically, senior leadership intended to balance resources across asset types and reduce the stock of infrastructure assets as well as the maintenance and repair budget while maintaining a constant level of service and operations (Culver, 2007). The incorporation of asset management functions at all vertical organizational levels (unit level, major command level, and headquarters level) created an emphasis on planning and implementing asset management principles in daily decision-making. Leadership of both the FHWA and the Air Force introduced the culture change of asset management into its organizations to efficiently manage infrastructure assets and maximize limited resources (Culver, 2007; United States Department of Transportation, 2003). Although the specific circumstances and details differed, the situations of both organizations paralleled each other. Both agencies required the strategic process of asset management to support their respective missions and organizational goals.

The comprehensive framework necessary to provide guidance for asset management business principles is absent from CE organizations despite a corporate structure culturally saturated with asset management; this absence results in a deficiency in decision making tools for CEs. A requirement exists for a comprehensive asset management framework that provides guidance for agencies with large, varying infrastructure sets and limited resources, such as the Air Force. This framework is

required to illustrate the relationships among the components of asset management and integrate these components into a useful, decision support system. This framework is also required to optimize the performance of infrastructure assets and provide decision-makers with the appropriate information to develop viable approaches and alternatives (Schofer, 2010). Thus, this paper introduces a comprehensive asset management framework for agencies with a large, varying infrastructure inventory and limited resources to conduct effective management of infrastructure assets. The purpose of the framework is to translate common and well established asset management philosophies into an implementable solution as shown with an Air Force case. This paper uses a representative sample of Air Force infrastructure as a case study to illustrate implementation of the comprehensive framework and relationships among the components of asset management in order to demonstrate the proposed framework's application and validity (Culver, 2007).

Infrastructure Challenges

Four challenges sparked the requirement for a comprehensive asset management framework: financial factors as opposed to technical factors, short-term planning as opposed to long-term planning, network as opposed to individual projects, and allocating resources across asset types (Vanier, 2001b). The financial factors, such as cost of maintenance and repair projects, are weighed against technical factors, such as structural quality of roofs and foundations, when implementing a solution. A shrinking budget and monetary cost of necessary projects exceeding the funds available for these projects exacerbate the constant challenge of financial constraints. Under these circumstances,

"asset managers must allocate funds among competing, yet deserving requirements" (Vanier, 2001a). Additionally, short-term remedies are evaluated against long-term goals. A short-term fix may not be the most economical solution and a long-term strategy may not be the timeliest solution (Vanier, 2000a). The difficulty in balancing short and long-term factors significantly increases with rapidly changing targets and goals. These challenges hinder the ability to assess and delineate short-term and long-term budgets and priorities, creating an increasingly difficult task.

Infrastructure is an integrated system with individual components that function independently and in conjunction with other systems (Vanier, 2000b). The interconnectedness of infrastructure links assets into a complex system of interrelated elements (Robinson, Woodard, and Varnado, 1998). This concept of infrastructure coupling correlates the state of one infrastructure asset to the state of another, which creates an interdependency between the two (Rinaldi, Peerenboom, and Kelly, 2001); however, most maintenance management systems (MMS) assess only individual components or isolated projects, instead of accounting for individual projects, network goals, and coupling effects. These individual projects are weighed against networks in which infrastructure is constrained by the weakest link or networks where parts should be replaced simultaneously in neighboring systems.

Last, budget constraints for maintenance and repair projects require decision-makers to allocate and balance resources across asset types while considering the value an asset has to an agency's operations and the current condition of the infrastructure. The difficulty in allocating resources across numerous types of infrastructure encompasses objective comparison among these assets of their worth and importance. Rapidly

changing leadership drives changing goals along with these issues create an increasingly challenging task, to delineate among assets and determine which assets require resource allocation. The contending factors of financial as opposed to technical, short-term planning as opposed to long-term planning, network as opposed to individual projects, and allocating resources across asset types provide challenges and opportunities for decision-makers and create a requirement for a comprehensive asset management framework for numerous infrastructure types that properly balances these aspects and guides the analytical process of asset management.

Data Modeling Process

Several strategic asset management models exist (e.g. Transportation Asset Management Guide); however implementing these frameworks into a useful, decision-making tool for Air Force asset management required the creation of a comprehensive data model, capable of implementing Air Force specific requirements. Thus, the researchers used Longley et al.'s data modeling process to create a comprehensive asset management framework that incorporates well understood components of asset management (Longley, Goodchild, Maguire, and Rhind, 2005). The method of data modeling is a type of systems modeling that defines and analyzes data requirements to support the business practices of an agency (Batini, Lenzerinim, and Navathe, 1986). Specifically, "a data model is a set of constructs for representing objects and processes in digital form" (Longley et al., 2005). A data model also involves ontologies, which define the components of a system and associate them in classes, relationships, or functions (Gruber, 2005). Data modeling consists of four levels (listed in order of increasing

abstraction): reality, conceptual model, logical model, and physical model (Longley et al., 2005).

Reality - Reality establishes an understanding of the systems and the interactions of its components (Longley et al., 2005; Sitzabee, Rasdorf, Hummer, and Devine, 2009). It also includes the aspects that are deemed applicable to the real-world construct.

Conceptual Model - The conceptual model is oriented toward its human users and is composed of selected objects and processes that are relevant to the problem domain (Longley et al., 2005; Sitzabee et al., 2009b). It identifies objects of significance, collects information, and describes associations between components.

Logical Model - A logical model is an implementation-oriented representation of reality and is depicted in diagrams and lists (Silverston, 2005). It depicts the entities, attributes, and relationships among the components of a system. The development of a logical model includes matching organizational functions with the specific data required to support each function as well as illustrating influential strategic components (Longley et al., 2005; Silverston, 2005). This type of model assists agencies in creating a common understanding of the business processes of asset management, data requirements, and maintenance and repair requirements across both vertical and horizontal boundaries.

Physical Model - A physical model is computer-oriented, portrays the actual implementation, and demonstrates how objects are digitally implemented (Longley et al., 2005; Sitzabee et al., 2009b). It describes the databases used to store data and identifies the data required for the process (Longley et al., 2005). This type of model assists agencies in achieving efficient access to data across the enterprise as well as integrity of data and security measures (Connolly and Begg, 2005).

Specifically for the scope of this paper, data modeling focuses on asset management processes for agencies with large, varying infrastructure sets and the data required to make decisions based upon the strategic components of these infrastructure systems. Ultimately, the goal of this paper is to evaluate Air Force asset management and guide the implementation of Next Generation Information Technology in order to create a decision support system for agencies with large, varying infrastructure inventories and limited resources.

Results

Logical Model

Development of the logical asset management model produced a comprehensive framework of an operational infrastructure system with numerous types of assets. This logical model consists of components, defined and described in the reality model and conceptual model phases, that are prevalent to the business practices of asset management. Figure 1 presents the logical model and graphically depicts influential strategic components as well as their relationships that are vital to the asset management process. It also illustrates the ontologies and associations among the asset management components and identifies the data required to promote analysis of infrastructure operations.

The strategic components illustrated in the logical model (Figure 1) formulate the process of asset management. Although relationships may differ according to organization, the basic artifacts of the asset management system are considered, defined, and discussed below.

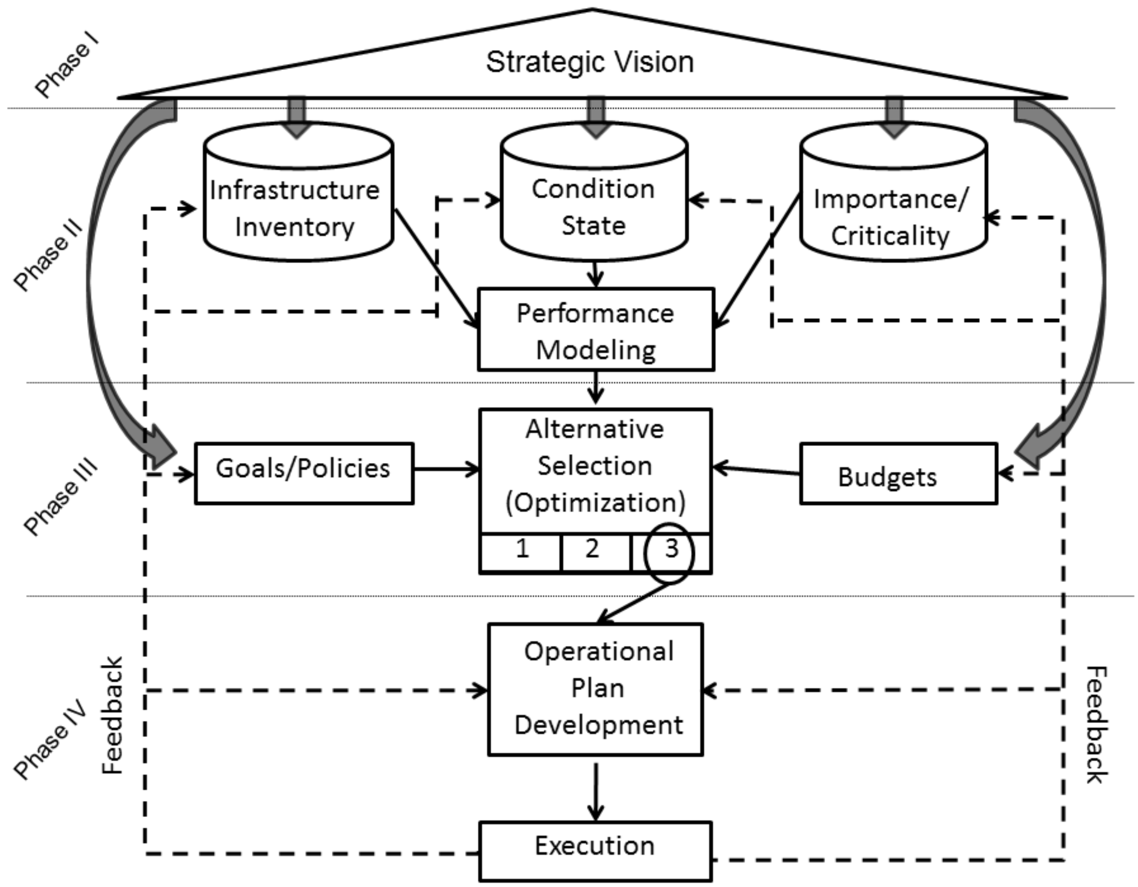

Figure 1. Logical Asset Management Model

The researchers tailored this logical model specifically to the Air Force's infrastructure operations using a representative sample of Air Force infrastructure to demonstrate the logical model's application and validity. Figure 2 presents the specific implementation of the general logical model (Figure 1) using the United States Air Force as the case. This same process could be applied to any agency with a large, varying infrastructure inventory and limited resources. Specifically, Figure 2 presents the Air Force case study of the logical model, which modifies the general logical model to the Air Force's asset management process, depicts the components as they pertain to this

specific organization, incorporates Air Force entities prevalent to each component, and identifies the data required for analysis of its infrastructure systems.

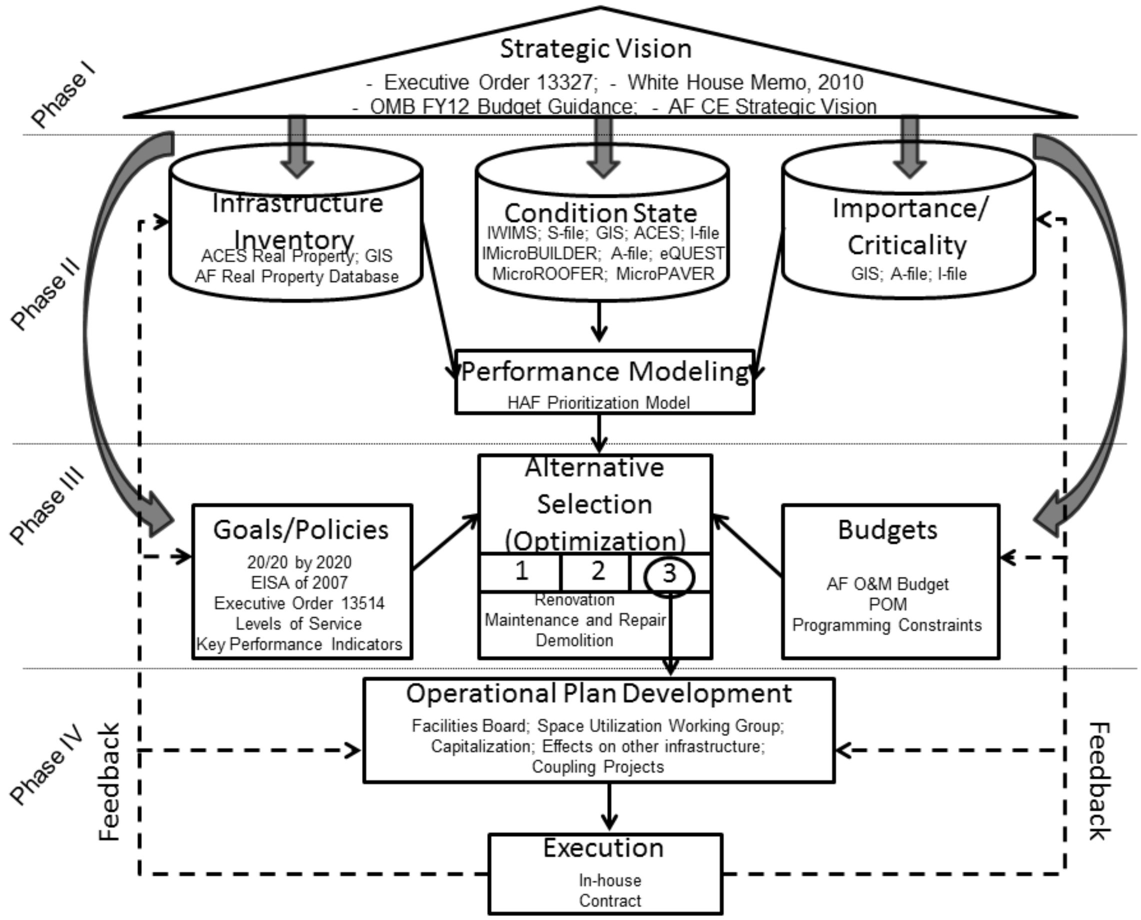

Figure 2. Logical Air Force Asset Management Model

The strategic asset management components depicted in the logical model (Figure 2) comprise the process of asset management for the Air Force. Each asset management artifact is further defined and discussed below to illustrate the specific Air Force application.

Phase I

Strategic Vision - Articulation and implementation of the strategic vision occurs both horizontally and vertically throughout the organization. Knowledge of the desired end state allows decision-makers to prudently dedicate resources to the operation, maintenance, and repair of infrastructure assets. This strategic vision creates an umbrella under which the operational aspects of data collection, budgets, policies, and goals can be aligned in order to utilize the latest asset management techniques (Australian National Audit Office, 1996).

Air Force Strategic Vision - National leaders and policy-makers establish the overarching strategic vision, specifically the White House and Congress influence the strategic visions of all federal agencies to include the Department of Defense (DoD) and the Air Force. DoD strategic level documents provide overarching guidance that the Air Force implements through its own strategic vision and operations. The Office of the Air Force CE, according to the strategic vision of the Air Force Civil Engineer career field, seeks to "provide…efficient, sustainable installations by using transformational business practices and innovative technologies" (Office of the Air Force Civil Engineer, 2011). This strategic vision highlights the use of asset management principles in daily operations and currently guides data collection, budgets, policies, and goals for the Air Force.

Phase II

Infrastructure Inventory - The purpose of maintaining an infrastructure inventory is to determine what assets are owned and where they are located (Vanier, 2001a).

Air Force Infrastructure Inventory - The Air Force owns an incredibly diverse set of constructed facilities and infrastructure assets ranging from dormitories to aircraft

hangars to warehouses (National Research Council, 1998). This infrastructure supports a myriad of government functions and is located on numerous continents. The age of the 139,556 infrastructure assets in the Air Force's inventory spans decades, and sometimes centuries, of building design and construction technologies (Department of Defense, 2010). The Air Force collects and maintains data for its infrastructure inventory with a valid set of data management systems in order to generate a snapshot of its assets; however considerable information technology (IT) issues exist because current data management systems do not effectively communicate with each other and data are entered multiple times into multiple data management systems (Thomas, 2009). For example, the Air Force Automated Civil Engineer System (ACES), which contains data regarding infrastructure operations such as maintenance and repair projects, hinders information flow because of its incompatibility with other maintenance management systems (MMS), such as Geographic Information System (GIS).

<u>Condition State</u> - Because infrastructure systems are in a constant state of decay, the condition state of an asset represents a snapshot of dynamic infrastructure assets (Government Accountability Office, 2007). The objective of collecting condition state data is to understand the current maintenance and repair required on infrastructure and to predict the future state of assets (Ugarelli, Venkatesh, Brattebo, Di Federico, and Saegrov, 2010).

<u>Air Force Condition State</u> - The Air Force collects condition state data in a MMS, the Interim Work Information Management System (IWIMS), tailored specifically for military operations. The Air Force also utilizes MicroROOFER for the condition state of roofs and MicroPAVER for the condition state of pavements, just to name a few. The

Air Force carries over approximately 9.3 billion dollars of maintenance and repair backlog each year, which amounts to 3.5 percent of its current replacement value (CRV) (Government Accountability Office, 2008). This quantity of deferred maintenance and repair is above the recommended industry standard of one to two percent residual from year to year (Government Accountability Office, 2008).

<u>Importance and Criticality</u> - An infrastructure asset's criticality characterizes its importance or business value to an agency's operations. Agencies collect infrastructure importance and criticality data to fulfill two objectives: to understand the impact that an incapacity or destruction of infrastructure assets would have on operations and to establish a relative order of significance among assets to allocate limited resources (Department of Homeland Security, 2009).

<u>Air Force Importance and Criticality</u> - The Air Force captures importance and criticality data to accurately assess the relative significance of assets when allocating and balancing limited resources and the impact on operations when assets are inoperable. The Air Force utilizes the mission dependency index (MDI), an infrastructure metric, to link the importance and criticality of infrastructure assets to the mission of an installation. Importance and criticality data enable decision-makers to understand the link between infrastructure assets and mission accomplishment.

<u>Performance Modeling</u> - Performance modeling is the primary tool to understand the maintenance and repair requirements of infrastructure systems (McElroy, 1999). The goal in shaping our maintenance and repair decision is to choose the most economical (from life-cycle standpoint) approach to answer the question, what should be fixed first? (Sitzabee, Hummer, and Rasdorf, 2009; Sitzabee et al., 2009b; Vanier, 2001a). These

tools, in essence, rely on accurate data to guide decisions that are related to the established strategic vision. Thus, a dependency exists between the performance modeling tool and the strategic vision to ensure that the measureable components of the tool provide decision-makers with the necessary information to align viable approaches with the strategic vision. The ultimate goal is to enable decision-makers to make informed, performance-based decisions that link the goals, policies, and budget to known aspects of system attributes (inventory, condition state, and importance and criticality) and performance (metrics and modeling tools).

<u>Air Force Performance Modeling</u> - Performance modeling for the Air Force serves as the primary tool to prioritize maintenance and repair requirements and utilizes an equation with infrastructure metrics to rank order projects. Headquarters Air Force developed the current performance modeling tool that prioritizes maintenance and repair projects. The Air Force also recently adopted an updated performance modeling tool for implementation in 2013.

<u>Phase III</u>

<u>Goals and Policies</u> - Goals and policies arise from and align with the strategic vision to convey how an agency is managing its assets as well as translate an organization's strategic vision into specific, relevant targets (Maunsell Project Management Team, 2006). These specific targets and focus items represent benchmarks that propel agencies toward achieving their desired, long-term objectives. Typically, agencies define their levels of service (LOS) in their goals and policies, which assist to shape targets and constraints of the system.

Air Force Goals and Policies - To align with the strategic vision of providing sustainable installations by using transformational business practices, the Air Force coined "20/20 by 2020" as its goal (Headquarters Air Force, 2009b). "20/20 by 2020" aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020 (Culver, 2007). The Energy Independence and Security Act (EISA) of 2007, which aims to reduce energy usage by 30 percent by the year 2015, Executive Order 13514, which aims to reduce potable water usage by 26 percent as well as non-potable water usage by 20 percent by the year 2020, and the "20/20 by 2020" goal are measureable targets that align with the Air Force strategic level vision (Congress of the United States, 2007; Headquarters Air Force, 2009b; Obama, 2009). These goals intend to reduce the Air Force's real property footprint to an optimal size and to incorporate energy and water conservation methods in the interest of optimizing the performance of infrastructure assets that support the warfighting mission (Byers, 2010). Ultimately, the Air Force is reducing the stock of infrastructure assets as well as the maintenance and repair budget while maintaining a constant level of service and operations. This Air Force infrastructure challenge that also applies to any agency with similar intiatives, reinforces the requirement for a comprehensive framework for numerous infrastructure types and limited resources to guide asset management decisions.

Budget - Budgets dictate the availability of resources for infrastructure projects. Budgets also constitute the single most significant constraint and as a result shape practically every decision.

Air Force Budget - Currently, the Air Force allocates 2.5 billion dollars annually to maintenance and repair projects (Department of Defense, 2010). This budget amounts to 0.95 percent of its CRV, which remains significantly lower than the recommended industry standard of two to four percent (Vanier, 2001b). Air Force regulations dictate the maximum amount available for various project types, such as a maximum amount of 750,000 dollars for minor construction, which imposes additional financial constraints. Allocating resources across asset types causes another budget issue for the Air Force. With limited resources available, decision-makers compare the worth and importance of infrastructure assets to determine which assets most require resource allocation.

Alternative Selection - Alternative selection explores options associated with infrastructure assets to determine which approach is in the agency's best interest. It entails examining and analyzing information from the performance modeling tool, goals, and policies as well as an understanding of financial constraints to determine the most advantageous solution. At this step in the comprehensive framework, the decision-makers decide upon the preferred resolution from the data provided (Cable and Davis, 2004).

Air Force Alternative Selection - Under the operations and maintenance budget, the Air Force examines four options for its infrastructure of demolish, maintain and repair, renovate, or construct an asset with capitalization (Department of Defense, 2001). The operations and maintenance budget funds demolition, maintenance and repair, as well as renovation projects. Capitalization, otherwise known as military construction (MILCON) constructs a new infrastructure asset that improves capability and corrects infrastructure

issues. However, MILCON falls under a separate budget with direct congressional oversight and approval; it does not compete with operations and maintenance funds.

Phase IV

Operational Plan Development - The purpose of operational plan development is to examine how the preferred course of action impacts an agency's infrastructure from a second and third order effect perspective. Once an optimal solution is determined, operational plan development considers how to leverage efficiency from infrastructure networks and how the proposed course of action affects other aspects of these assets (Coullahan and Siegfried, 1996).

Air Force Operational Plan Development - Along with addressing how the optimal solution affects current maintenance and repair projects, planning for future endeavors such as space utilization as well as future maintenance and repair projects occurs as a part of operational plan development. The preferred course of action requires consideration for bundling projects together to gain time and cost efficiencies; projects can be performed on connected, neighboring infrastructure systems and parts can be replaced simultaneously (National Research Council, 1998), such as completing an airfield lighting project while simultaneously executing a pavement project on a runway.

Execution – Preventive maintenance, reactive maintenance, project implementation, and demolition occurs during execution. The intent of execution is to synchronize the previously discussed components in order to complete projects (Cable and Davis, 2004).

Air Force Execution – In the case of the Air Force, execution involves coordinating the labor and funding to carry out the demolition, maintenance and repair projects, and/or

renovation. Execution implements the optimal solution to utilize limited resources in the most effective manner in order to optimize the performance of infrastructure assets.

Feedback - Asset management frameworks are iterative, and the feedback loop allows for this cyclic process to reflect upon past efforts and start again (National Association of College and University Business Officer, 1995). The initial cycle through this comprehensive asset management framework provides the basis for subsequent cycles and influences future decisions (Maunsell Project Management Team, 2006). Once a project is executed, decision-makers analyze the results, address any issues, and start to work through the framework again at the appropriate phase.

Air Force Feedback - Asset management for the Air Force is an iterative process that requires a feedback loop. The strategic vision, goals, and policies are in constant flux with the continual movement of headquarters staff personnel and commanders. Additionally, the operations and maintenance budget varies from year to year (Government Accountability Office, 2007). Thus, Air Force decision-makers examine results and address changes during feedback, prior to beginning the iterative process of asset management again.

The logical asset management model presented in Figure 1 creates a comprehensive framework that provides guidance for the asset management process. It serves as a useful, decision-making tool that is applicable to agencies with a large, varying infrastructure inventory and limited resources. This framework enables decision-makers to formulate viable approaches and alternatives to infrastructure management and facilitates efficient use of the annual operations and maintenance budget in order to optimize the performance of infrastructure assets.

The logical Air Force asset management model, presented in Figure 2, creates a decision-making framework for the Air Force that guides the analytical process of asset management and addresses infrastructure challenges, specifically for this organization. This case study of the comprehensive asset management framework confirms its generalizability to agencies with a large, varying infrastructure inventory and limited resources. It also affirms that agencies are able to tailor the general logical model to infrastructure systems of a particular organization, which establishes the framework's usability and utility for agencies with similar infrastructure characteristics and budget constraints. The final step in the data modeling process consists of developing a physical model that utilizes the relationships among asset management components and their ontologies. Physical models are tailored to the specific infrastructure operations of individual agencies and their data requirements in order to compile the information for the performance modeling tools. This paper purposefully excludes the Air Force physical model that guides the implementation of Next Generation Information Technology due to its lack of applicability and generalizability to other agencies with similar infrastructure characteristics and budget constraints.

Air Force Performance Modeling

The logical model highlights the disconnect between the performance modeling tools (current and recently adopted) and the established goals, resulting in the requirement for an improved performance modeling tool that aligns with the strategic vision, goals, and policies of the Air Force. The comprehensive asset management framework developed for numerous infrastructure types (Figure 1) evaluated the current

(Equation (1)) and recently adopted (Equation (2)) performance modeling tools. The Air Force currently uses Equation (1) to prioritize maintenance and repair projects (Headquarters Air Force, 2009a).

$$\text{Priority} = (\textit{Facility Condition Index} \times \textit{Mission Dependency Index}) +/- \textit{Commander Adjustment} \quad (1)$$

The primary limitation the Air Force encounters during alternative development is the discontinuity between the measureable metrics of the “20/20 by 2020”, Energy Independence and Security Act (EISA) of 2007, and Executive Order 13514 goals and the infrastructure metrics of the current performance modeling tool (Byers, 2010; Congress of the United States, 2007; Culver, 2007; Headquarters Air Force, 2009b; Obama, 2009). The “20/20 by 2020” goal aims to reduce both the physical square footage of Air Force infrastructure as well as maintenance and repair costs by 20 percent by the year 2020, the EISA (2007) goal aims to reduce energy usage by 30 percent by the year 2015, and Executive Order 13514 aims to reduce potable water usage by 26 percent as well as non-potable water usage by 20 percent by the year 2020; however, the current priority equation, Equation (1) (performance modeling tool), prioritizes projects with condition state and infrastructure inventory information based on each infrastructure’s economic health and importance to operations (Facility Condition Index (FCI) and Mission Dependency Index (MDI)). This equation does not consider or account for the objectives of the “20/20 by 2020”, EISA (2007), or Executive Order 13514 goals (reduction in square footage, energy usage, and water usage); it does not currently include energy, water, or square footage infrastructure metrics that the Air Force goals

strive toward. This disconnect between the current performance modeling tool (Equation (1)) and goals results in decision-makers selecting an optimal solution based upon either the goals or the priority equation, but not both. This disconnect also results in competing interests and a lack of synergy between the goals and current performance modeling tool (Equation (1)). Thus, the priority order generated by the current tool does not align with the established Air Force goals, which creates a disconnect from the comprehensive framework and the relationships among asset management components depicted in the framework.

Additionally, decision-makers will utilize the current Air Force performance modeling tool (Equation (1)) to prioritize maintenance and repair projects until implementation of the recently adopted performance modeling tool (Equation (2)) in 2013 (Headquarters Air Force, 2011).

$$\text{Priority} = 0.15(\textit{Health, Safety and Compliance}) + 0.10(\textit{Facility Condition Index} \times 100) + 0.15(\textit{Standardized Mission Dependency Index}) + 0.20\,(\textit{Local Mission Impact}) + 0.15(\textit{Cost Efficiency}) + 0.25(\textit{Service Quality}) \tag{2}$$

The recently adopted performance modeling tool (Equation (2)) also accounts for the asset management components of infrastructure inventory, condition state, as well as importance and criticality by including the infrastructure metrics of FCI, standardized MDI, and local mission impact; however, the Air Force encounters a limitation with the recently adopted performance modeling (Equation (2)) tool during alternative development because this tool combines energy and space utilization goals into one infrastructure metric, cost efficiency, and does not include a water usage metric. Although the cost efficiency metric aligns with the established energy and space

utilization goals, it does not balance these goals to ensure that each goal is achieved. Once again, the priority order generated by the recently adopted performance modeling tool (Equation (2)) does not align with all of the established Air Force goals, which also creates a disconnect from the comprehensive asset management framework and the relationships among asset management components depicted in the framework. Thus, an improved performance modeling tool that incorporates energy, water, and space utilization infrastructure metrics is necessary for the Air Force to objectively prioritize maintenance and repair projects, compare various types of infrastructure at different locations, and generate master priority lists for Air Force infrastructure assets.

Improper Linear Modeling Process

The researchers used Dawes's improper linear modeling process to develop an improved performance modeling tool that aligns with the Air Force strategic vision, goals and policies (Dawes, 1979). The method of improper linear modeling allows experts to define the independent variables and weight these variables to build a linear function. This function determines the best relationship between the independent variables and a dependent variable based upon experts' judgments (Dawes and Corrigan, 1974). The improper linear modeling process typically consists of several steps including initial examination of independent variables, selection of independent variables, model development, and model verification (Dawes, 1979).

Initial Examination of Independent Variables – Examination of infrastructure metrics provided an understanding of the possible independent variables and how they are measured or calculated (Cook, 1977). An examination of their relationships occurred

during this step as well to determine the effects resulting from the connections between independent variables (Cook, 1979).

Selection of Independent Variables – This step established the purpose and goals of the improved modeling tool (George, 2000). These objectives provided selection criteria for the independent variables and a specific target for the dependent variable. Selecting and identifying independent variables to include in the improved tool required aligning the purpose of the improved performance modeling tool with the strategic vision, goals, and policies of the Air Force.

Model Development - The selected variables from step two produce a linear function or improper linear model. The development step assigned weights to these independent variables, so that the improper linear model consists of independent variables, each multiplied by a weight and then added together (Goldberger, 1962). Additionally, the sum of the weights and boundary conditions were examined to ensure they satisfied the criteria for an improper linear model.

Model Verification - The purpose of this verification was to establish the usefulness of the improved performance modeling tool for the Air Force in order to generalize this tool to any installation in the inventory; and ultimately objectively prioritize maintenance and repair projects across various types of infrastructure assets. This improper linear model was verified with asset management experts, who discussed, compared, and analyzed the advantages and disadvantages of the infrastructure metrics as well as priority orders produced by the current, recently adopted, and improved performance modeling tools.

Results

Improved Air Force Performance Modeling Tool

Development of the improved Air Force performance modeling tool (Equation (3)) produced an equation of infrastructure metrics that aligns with the strategic vision, goals, and policies of the Air Force to objectively prioritize maintenance and repair projects for numerous infrastructure types. This improved performance modeling tool (Equation (3)) consists of infrastructure metrics that incorporate the principles of asset management as well as the established goals of the Air Force. Equation 3 presents the improved tool developed through the improper linear modeling process.

$$\text{Priority} = 0.35(\textit{Asset Level Mission Dependency Index}) + 0.35(\textit{Facility Condition Index} \times 100) + 0.10(\textit{Energy}) + 0.10(\textit{Water}) + 0.10(\textit{Space Utilization}) \tag{3}$$

The researchers selected each independent variable in Equation (3) intentionally and for a purposeful reason to ensure mission accomplishment as well as align the tool with the established Air Force strategic vision and goals. For instance, the asset level MDI was selected to maintain a link between infrastructure and mission accomplishment at the asset level across the Air Force. This infrastructure metric incorporates differences in mission and idiosyncrasies in infrastructure operations from one installation to another as well as accounts for interdependencies among infrastructure assets, intradependencies within infrastructure assets, and the scope of operations affected by the inoperability of a particular asset. This infrastructure metric derives interdependency and intradependency scores from the responses to structured interview questions with numerous decision-makers' to formulate a statistically sound MDI score from their judgments and the

number of missions impacted (Antelman, 2008). The asset level MDI metric allows decision-makers to utilize their expertise and account for infrastructure challenges that are distinct to each installation. Also, this metric captures the importance and criticality of an infrastructure asset in a statistically sound manner that has already been tested, proven, and implemented with the United States Navy, United States Coast Guard, National Park Service, and the National Aeronautical and Space Administration (Antelman, 2008). Thus, the MDI infrastructure metric accommodates the interdependencies and intradependencies intrinsic to coupled infrastructure and accounts for decision-makers' risk tolerances to communicate the link between an asset and the mission, which is one critical component to objectively prioritizing maintenance and repair projects and allocating limited resources across numerous types of infrastructure assets.

The FCI was selected to include the condition state (deferred maintenance and repair and current replacement value) of infrastructure assets into the priority score. Specifically, this infrastructure metric provides a representation of the deferred maintenance and repair work in comparison to the current replacement value of infrastructure. Although the numerator of the FCI metric can be influenced by decision-makers, it provides a benchmark with simple calculations and minimal data collection to compare the relative condition of infrastructure assets. The alternative to the FCI metric is to physically assess each component (e.g. roof, electric) of each infrastructure asset. Although this alternative provides precise condition state data, intermittent data maintenance, collection, and updates are required to ensure that the data accurately reflect the condition of each infrastructure component. The tremendous cost and manpower

required to accurately capture and maintain component condition state data for the Air Force's 139,556 infrastructure assets would significantly reduce the budget for maintenance and repair projects. A balance must be achieved between the cost and labor required to maintain the condition state data and the accuracy of the data itself. The FCI provides this balance because of its ability to achieve a fairly accurate representation of a relative condition state in comparison to other infrastructure assets using simple calculations and minimal data collection. It also aligns with the Air Force strategic vision and allows infrastructure assets to remain within industry standards.

Additionally, energy, water, and space utilization were selected as independent variables to align the improved performance modeling tool (Equation (3)) with the established goals and policies of the Air Force. The energy infrastructure metric incorporates the EISA (2007) goal, the water infrastructure metric incorporates the Executive Order 13514 goal, and the space utilization infrastructure metric incorporates the "20/20 by 2020" goal into the improved priority equation. There is an infrastructure metric for each of these goals to balance these goals and ensure that each goal is achieved. These infrastructure metrics should adjust as the established goals of the Air Force change or as additional infrastructure goals are added to allow the improved performance modeling tool (Equation (3)) to reflect the current goals of the Air Force.

The 2008, 2009, and 2010 Air Force Real Property databases were examined to determine the appropriate weights for the independent variables in Equation (3). Assigning the metric categories, asset level MDI, FCI, and established goals (energy and space utilization), approximately a third of the weight ensures that each category is equally taken into consideration when formulating the priority order. The asset level

MDI independent variable was assigned 35 percent of the overall priority score to emphasize the link between infrastructure assets and mission accomplishment. Additionally, the FCI independent variable was assigned 35 percent of the overall priority score. The emphasis on the condition of infrastructure allows assets to remain within industry standards. Last, the energy independent variable was assigned 10 percent, the water independent variable was assigned 10 percent, and the space utilization independent variable was also assigned 10 percent. These three metrics range from zero to 100 and default to 50 points if a project does not affect energy usage, water usage, and space utilization. If a project decreases energy usage, water usage, and/or utilizes space in a more efficient manner, then the project receives more than 50 points for the metrics (one, two, or three) that the project positively affects. If a project increases energy usage, water usage, and/or utilizes space in a less efficient manner, then the project receives less than 50 points for the metrics (one, two, or three) that the project negatively affects. This incorporation of energy usage, water usage, and space utilization metrics considers the established Air Force goals and prioritizes projects across numerous infrastructure types to ensure the achievement of these goals.

The improved performance modeling tool (Equation (3)) fulfills the two mandatory criteria for improper linear models. First, the assigned weights sum to 100. Second, the boundary conditions are maintained with zero as the minimum priority score and 100 as the maximum priority score. Additionally, the improved performance modeling tool (Equation (3)) accounts for the asset management components of infrastructure inventory, condition state (FCI), importance and criticality (MDI), and goals (energy, water, and space utilization), aligns these components with the Air Force

strategic vision, and addresses infrastructure challenges, which stems from the decision support system for numerous infrastructure types created by the comprehensive asset management framework. The improved performance modeling tool (Equation (3)) achieves a delicate balance between accuracy of data to generate an objective priority score and the cost as well as labor required to generate that score by selecting infrastructure metrics that consider this balance, specifically target particular asset management components, and are compatible with Next Generation Information Technology initiatives. The current performance modeling tool (Equation (1)) lacks accuracy of data by utilizing infrastructure metrics that require minimal data maintenance and cost to generate a priority score. The recently adopted performance modeling tool (Equation (2)), on the other hand, obtains accuracy of data by requiring a tremendous amount of manpower and a large budget to generate a priority score. Table 1 summarizes these aspects (low cost data collection and maintenance, data accuracy, condition state, importance and criticality, as well as established Air Force goals) for the current, recently adopted, and improved Air Force performance modeling tools to illustrate the characteristics that each priority equation possesses and the differences amongst the performance modeling tools.

Table 1. Summary of Air Force Performance Modeling Tools

Characteristic	**Current Performance Modeling Tool (Equation (1))**	**Recently Adopted Performance Modeling Tool (Equation (2))**	**Improved Performance Modeling Tool (Equation (3))**
Low Cost Data Collection and Maintenance	X		X
Data Accuracy		X	X
Condition State	X	X	X
Importance and Criticality	X	X	X
20/20 by 2020 goal		X	X
Energy Independence and Security Act of 2007 goal		X	X
Executive Order 13514 goal			X

The improved performance modeling tool (Equation (3)), thus, eliminates the disconnect between the current and recently adopted performance modeling tools and the strategic vision as well as established goals of the Air Force by prioritizing maintenance and repair projects according to the strategic vision and established goals. It also balances between accuracy of data and the cost as well as labor required to generate a priority order for maintenance and repair projects. The improved performance modeling tool (Equation (3)) fulfills the requirement for an improved tool that better prioritizes maintenance and repair projects across numerous infrastructure types at different locations, manages infrastructure according to the business principles of asset management, and effectively utilizes the limited operations and maintenance budget. Ultimately, the improved performance modeling tool (Equation (3)) allows decision-makers to prioritize maintenance and repair projects in order to objectively compare various types of infrastructure at different locations and generate master priority lists for Air Force infrastructure assets.

Key Findings

The analysis conducted during this research effort highlights two key findings that pertain to the Air Force, but also apply to agencies with similar infrastructure characteristics and budget constraints. First, a discontinuity exists between the established Air Force strategic vision, goals, and policies and the current (Equation (1)) as well as recently adopted (Equation (2)) performance modeling tools. The purpose of performance modeling is to understand the maintenance and repair requirements of infrastructure assets and allow this information to shape decisions; however the current

and recently adopted Air Force performance modeling tools do not align with the organization's strategic vision, goals, and policies (McElroy, 1999). The previous section, Air Force Performance Modeling, thoroughly discussed this key finding.

Second, the data and maintenance management system (MMS) required for strategic level asset management do not align with the data and MMS required for tactical level asset management due to a lack of enterprise-wide data and an enterprise level MMS to manage the data. The strategic level forecasts, requests, and justifies a long-term budget for demolition, renovation, capitalization, and maintenance and repair projects with a 10 to 12 year outlook; however the tactical level allocates the operations and maintenance budget and advocates for short-term requirements with a one to two year outlook. The tactical level (Air Force installations) funnels data, usually in a MMS, up to the strategic level based on its own outlook. Likewise, the strategic level (Headquarters Air Force) funnels data, usually in a MMS, down to the tactical level based on its own outlook. The top-down data transfer does not consider the tactical level outlook and the bottom-up data transfer does not consider the strategic level outlook. This disparity stems from differences in operations between the two levels. Long-term planning is not a concern of the tactical level because its focus is on short-term execution, but a lack of information regarding long-term requirements results in a lack of requests for and justification of future budgets. As a result, an adequate amount of operations and maintenance funds will not be available for projects in 10 years, when what was the long-term is now the short-term. Short-term execution is also not a concern of the strategic level because its focus is on long-term planning and the funds for short-term execution have already been allocated to installations across various asset types.

Additionally, the Air Force Civil Engineer community collects data for, utilizes, and maintains over 10 MMS. At times, the MMS utilized by the strategic level is not the same MMS utilized by the tactical level. In these instances, the lack of compatibility between data formats hinders the top-down, bottom-up flow of data. Air Force efforts should align the data and MMS required for strategic level asset management with the data and MMS required for tactical level asset management, which is precisely what the comprehensive asset management framework achieves. The framework streamlines communication, aligns data requirements between vertical as well as horizontal levels, and formulates resolutions that are in the best interest of all levels. Aligning the required data and MMS enables transparency of data and streamlines data collection and maintenance for efficient and effective database management. The comprehensive asset management framework for numerous infrastructure types achieves the ultimate goal of data management, to align the MMS and required data for asset management in order for decision-makers to conceive of approaches and alternatives that are in the best interest of all vertical (tactical, operational, and strategic) levels of the Air Force.

The discontinuity that exists between the performance modeling tools (Equation (1) and Equation (2)) and the Air Force's strategic vision, goals, and policies as well as the differences in MMS and data required between the strategic and tactical levels causes misaligned data management at both horizontal and vertical levels. This misalignment resulting from the disparities in data and asset management components is illustrated in Figure 3.

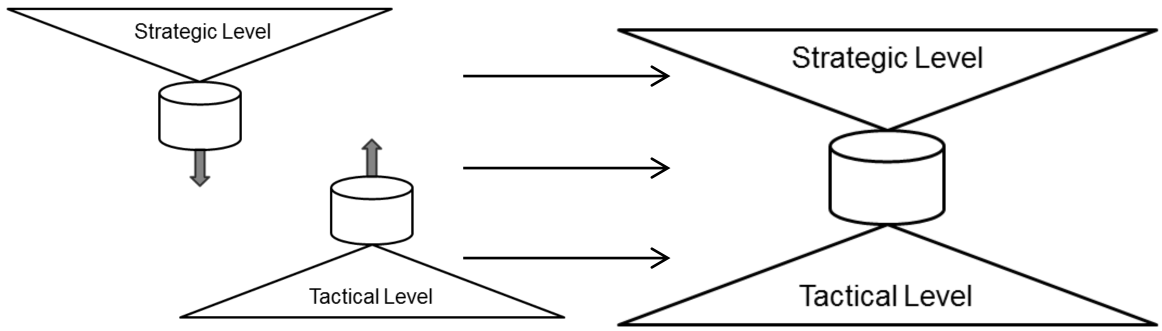

Figure 3. Data Disparity and Alignment between Strategic and Tactical Levels

Equation (3) provides a solution to the discontinuity between the Air Force performance modeling tools, Equation (1) and Equation (2), and the strategic vision, established goals, and policies by developing an improved performance modeling tool, Equation (3). Additionally, this research effort aligns the required data and MMS between the strategic and tactical levels by developing a comprehensive asset management framework. Mitigating these disparities aligned data and asset management components both at horizontal and vertical levels for the Air Force, which allows for a single enterprise level database. The development of an Air Force enterprise level database embodies several pillars of the Next Generation Information Technology Program Management Plan to include the elimination of redundant data entry, the simplification of data calls, as well as streamlined data collection, maintenance, and visibility of data at all vertical levels. The creation of a single enterprise level database for the Air Force also furthers the implementation of asset management business practices. Figure 3 presents the streamlined top-down, bottom-up approach created by

the products of this research effort in order to effectively manage and allocate resources across numerous types of infrastructure assets.

Additionally, figure 3 illustrates a single enterprise level database (e.g. oracle and structured query language) with common data that align the strategic and tactical levels both vertically and horizontally. Ideally, this database serves various software systems (e.g. Geographic Information System) that the Air Force utilizes and interprets the format to create useful products. This approach of Information Technology integration allows the tactical level to provide the strategic level with data that are applicable to its focus area and vice versa. It also allows the strategic level to provide the tactical level with data that are applicable to its focus area; instead of the current situation where the tactical and strategic levels provide the other with information that applies to their own outlook. Thus, the focus areas and outlooks of the strategic level and tactical level vary due to the differences in operations of these functional levels; however efficient operations and maintenance of infrastructure requires alignment of data in order to optimize the performance infrastructure assets. The International Infrastructure Maintenance Manual reinforces the concepts discussed of aligning required data and MMS as well as depicts the requirement to align the strategic and tactical levels of an organization with common data (Maunsell Project Management Team, 2006). It also highlights the streamlined top-down, bottom-up approach to infrastructure asset management.

This paper identifies two requirements that were fulfilled by developing a comprehensive asset management framework for numerous infrastructure types, using the data modeling process, and an improved Air Force performance modeling tool, using the improper data modeling process. The utility of this research effort lies in its two products

that contribute toward the asset management body of knowledge and optimize the performance of numerous infrastructure types at various locations. First, a comprehensive asset management framework that provides guidance for asset management business principles, specifically for agencies with a large, varying infrastructure inventory and limited resources. Second, an improved Air Force performance modeling tool allows decision-makers to prioritize maintenance and repair projects in order to objectively compare various types of infrastructure at different locations and generate master priority lists for Air Force infrastructure assets. The paper discusses two key findings, data disparities both at horizontal and vertical levels as well as a performance modeling tools that do not account for Air Force goals. The products of this research effort, a comprehensive asset management framework for numerous infrastructure types and an improved performance modeling tool, Equation (3) align data at all levels to streamline the top-down, bottom-up flow of information and reflect the strategic vision, goals, and policies of the Air Force. The Air Force infrastructure case study, utilized throughout this paper, illustrated the implementation of the comprehensive asset management framework to demonstrate the proposed framework's utility in identifying the two key findings. Thus, agencies with a large, varying infrastructure inventory and limited resources are able to apply the comprehensive asset management framework to the specific infrastructure operations of their organizations to conduct comprehensive management of infrastructure assets.

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Vita

1st Lt Marie T. Harnly graduated from Stanford University with a Bachelor of Science degree in Mechanical Engineering and a Bachelor of Arts degree in Spanish in June 2008. She was commissioned through Air Force Reserve Officers' Training Corps Detachment 045 at San Jose State University. Her first assignment was at Sheppard Air Force Base, Texas, where she held the positions of Project Engineer for the 82d Civil Engineer Squadron, Executive Officer for the 82d Mission Support Group, and Special Assistant/Project Officer to the Commander for the 82d Training Wing. In August 2010, she entered the Graduate School of Engineering and Management, Air Force Institute of Technology, where she earned a Master of Science degree in Engineering Management. Upon graduation, she will be assigned to the 628th Civil Engineer Squadron, Joint Base Charleston, South Carolina.

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14. ABSTRACT Effective asset management requires an overarching model that establishes a framework for decision-makers. This research project develops a strategic level asset management model for varying types of infrastructure that provides guidance for effective asset management. The strategic model also incorporates Next Generation Information Technology initiatives into a single coherent system to streamline the top-down, bottom-up flow of information. The strategic model is applicable to agencies with a large, varying infrastructure inventory and limited resources. This research also develops an improved performance modeling tool, a critical component of the strategic model. This tool objectively prioritizes maintenance and repair projects according to measurable metrics as well as the strategic vision, established goals, and policies. Asset management of Air Force infrastructure provides an example of applicability for this strategic model and improved tool; thus, an asset management example of Air Force infrastructure is utilized throughout the research project to demonstrate the utility of the model and the tool. The strategic level model and improved tool enable policy-makers to make decisions that tie goals, infrastructure inventory, condition state, importance and criticality, and budget constraints to system performance. As a result, insight is gained on ways to maximize efficiency and optimize the performance of infrastructure.			
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